

**GEOLOGICAL AND GEOCHEMICAL ASPECTS
OF THE LIONTOWN VHMS DEPOSIT
NORTH EASTERN QUEENSLAND**

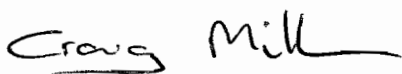
By:

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**Submitted in partial fulfilment of the requirements
for the degree of M.Econ.Geol.
University of Tasmania
July 1996**

Declaration

This thesis contains no material which has been previously accepted for any degree or graduate diploma. To the best of my knowledge the thesis does not contain material previously published or written by another person except when due reference is made in the text of the thesis.

A handwritten signature in black ink, appearing to read "Craig Miller", written over a horizontal dotted line.

Craig R Miller

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ABSTRACT

The Liontown VHMS deposit lies in the central portion of the 165km long, E-W trending, narrow belt of deformed Cambro-Ordovician marine sediments and volcanics known as the Mount Windsor subprovince of northeastern Queensland.

Liontown is shown to be a volcanic-associated massive sulphide deposit comprising both seafloor exhalative and subhalative mineralisation. Metal zonation studies suggest the exhalative mineralisation was vented onto the seafloor on the edge of a paleo ridge and migrated down slope to the west and southeast. Sulphur, lead, oxygen and carbon isotope data is consistent with a VHMS parentage.

The Liontown deposit is temporally associated with the change from dacitic to rhyolitic volcanism and may have a more shallow water setting than previously considered. The Carrington Lode at Liontown is a sub-seafloor replacement body interpreted to have formed by the eastward lateral migration of hydrothermal fluids preferentially through an ashy and feldspar bearing volcanoclastic horizon. The associated black Mg-chlorite alteration is inferred to mark a zone of seawater-hydrothermal fluid mixing.

The application of stable isotope and rare earth element (REE) analyses to provide “vectors” to mineralisation is investigated in the thesis. The whole rock oxygen isotope data collected along the footwall alteration system indicates that this technique has good vectoring potential to zones of elevated hydrothermal temperature. Refinement of the raw data through the calculation of relative temperature estimates is demonstrated as an important data manipulation procedure, particularly for data sets where the sample mineralogy is highly variable.

The Liontown carbonate exhalative facies and the sericitic siltstones of the ‘favourable horizon’ each have positive europium anomalies ($\text{Eu}/\text{Eu}^* > 1$). In the immediate Liontown deposit area a proximal to distal trend was observed in the carbonate europium data set suggesting there is some scope to develop the intensity of Eu/Eu^* as a vectoring tool.

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1. INTRODUCTION

Pancontinental Mining Limited (Pancon)/RGC Exploration Pty Ltd have been exploring the Mount Windsor subprovince in North Eastern Queensland for volcanic-hosted massive Sulphide (VHMS) mineralisation since acquiring the Thalanga deposit in late 1987. In October 1993, Pancon purchased the Liontown deposit and surrounding mining leases. This gave Pancon access to the highly prospective Liontown district and also provided a unique opportunity to study the Liontown deposit which occurs high in the prospective stratigraphy at, or near, the top of the Trooper Creek formation.

The initial intent of the research was to focus on the carbonates associated with the stratiform base metal sulphides. However during the study period the subhalative Carrington lode was recognised and the project grew into a more general investigation of the entire deposit. As the study progressed an emphasis on the application of various less conventional geochemical techniques as a means of finding additional vectors to mineralisation was developed.

The specific aims of the research can now be summarised as follows:

- a. To document and elucidate the geological setting and controls on the Liontown exhalative and subhalative Cu-Pb-Zn-Au-Ag mineralisation, including;
 - i. Descriptive documentation of the peripheral alteration/mineralised systems (Tigertown, Cougartown, Leopardtown and Panthertown) from surface sampling and core logging and interpretation of their relationship to the Liontown system.
 - ii. To study the metal zonation patterns from assay data of both the exhalative and subhalative mineralisation to assist in defining vent zones/areas of focused metal accumulation.
 - iii. The footwall succession at Liontown has been variously described as phyllites and mica schists by Levingston (1972) and pyroclastics and dacites by McLean (1985). To clarify the confusion, the study incorporates an attempt to determine the nature of the protolith and examine the relationship between the Carrington

lode and the chloritic-feldspar phyric schists previously referred to by McLean as the "footwall dacite".

- iv. To further develop an understanding of the controls on the exhalative stratiform mineralisation, isopach mapping of the exhalative package and 3D reconstruction/modelling of the paleo sea-floor topography has been pursued.
- b. The application of stable isotope and rare earth element (REE) analyses to provide "vectors" to mineralisation and to further characterise the nature of the hydrothermal system, including;
 - i. The lateral variation of REE's in the hydrothermally altered siltstones of the Time Equivalent Horizon.
 - ii. Investigation of europium depletion patterns within the footwall alteration system.
 - iii. The use of whole rock oxygen isotope analyses of siliceous footwall lithologies, and the application of relative temperature calculations to enhance the vectoring capacity of the analyses.

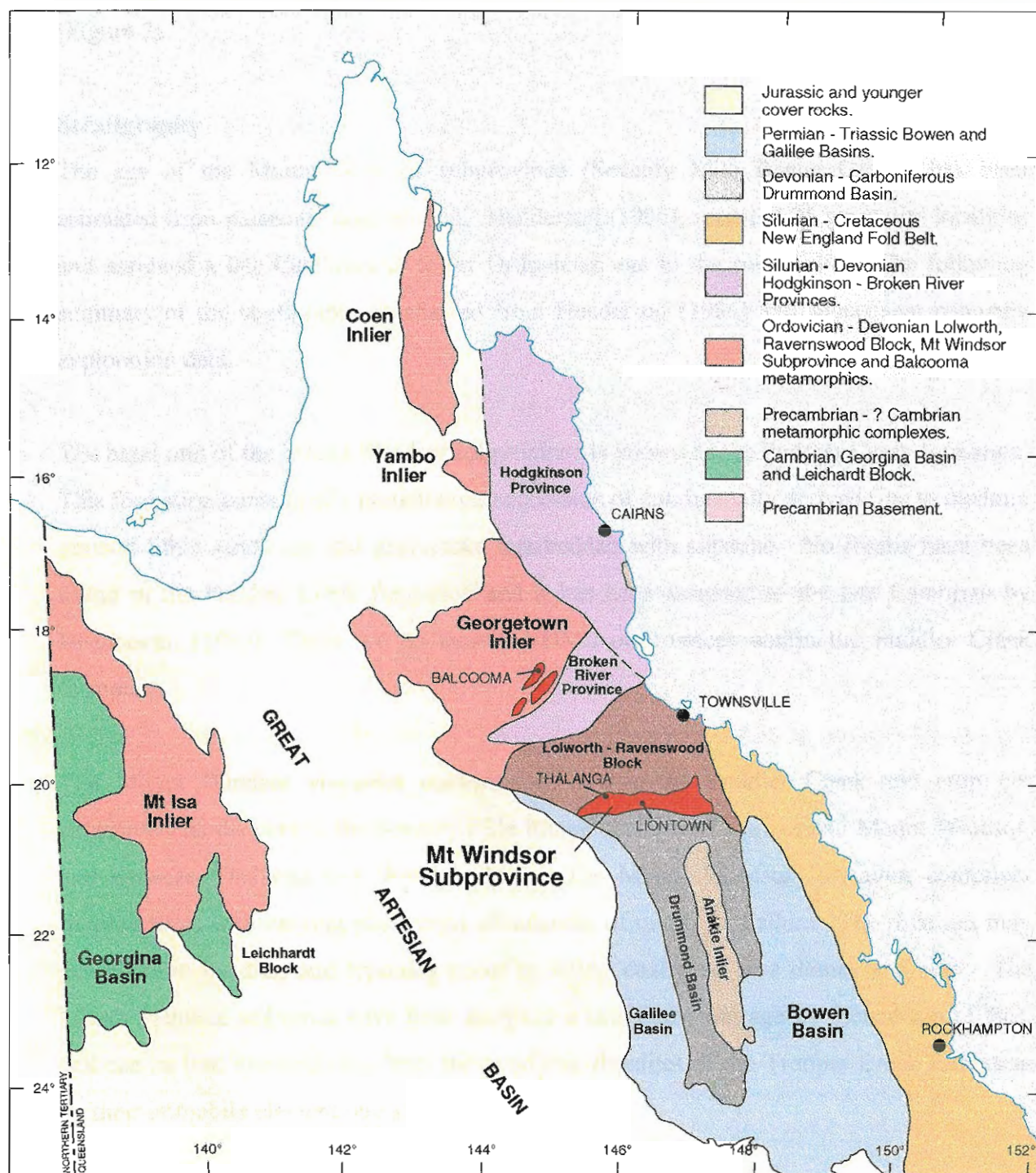
2. LOCATION AND ACCESS

Liontown is situated 42 kilometres southwest of Charters Towers, North Queensland. Access is provided by the sealed Charters Towers - Clermont road (23km) and a well-graded property road (19km). From Thalanga, the project area is located 30km to the ESE. At the time of writing, Pancontinental Mining Limited/RGC held 100% interest in 35 MLs totalling 37.8km² at Liontown.

3. REGIONAL GEOLOGICAL SETTING

The Liontown VHMS deposit lies in the central portion of the 165km long, E-W trending, narrow belt of deformed Cambro-Ordovician marine sediments and volcanics known as the Mount Windsor subprovince (Figure 1). The subprovince is also host to other VHMS

NORTHERN QUEENSLAND GEOLOGY MAP



deposits such as Thalanga, Highway-Reward, Waterloo, Magpie and Warrawee (Berry et al, 1992). The stratigraphic sequence is largely conformable, has an exposed thickness of up to 10km, faces south and comprises (in ascending order) the Puddler Creek, Mount Windsor, Trooper Creek and Rollston Range formations. To the north the Mount Windsor subprovince is disrupted and intruded by the Ordovician-Devonian Ravenswood Granodiorite Batholith. In the south the Rollston Range formation becomes obscured by the onlapping Carboniferous strata of the Drummond Basin terrestrial volcanics and sediments (Figure 2).

3.1 Stratigraphy

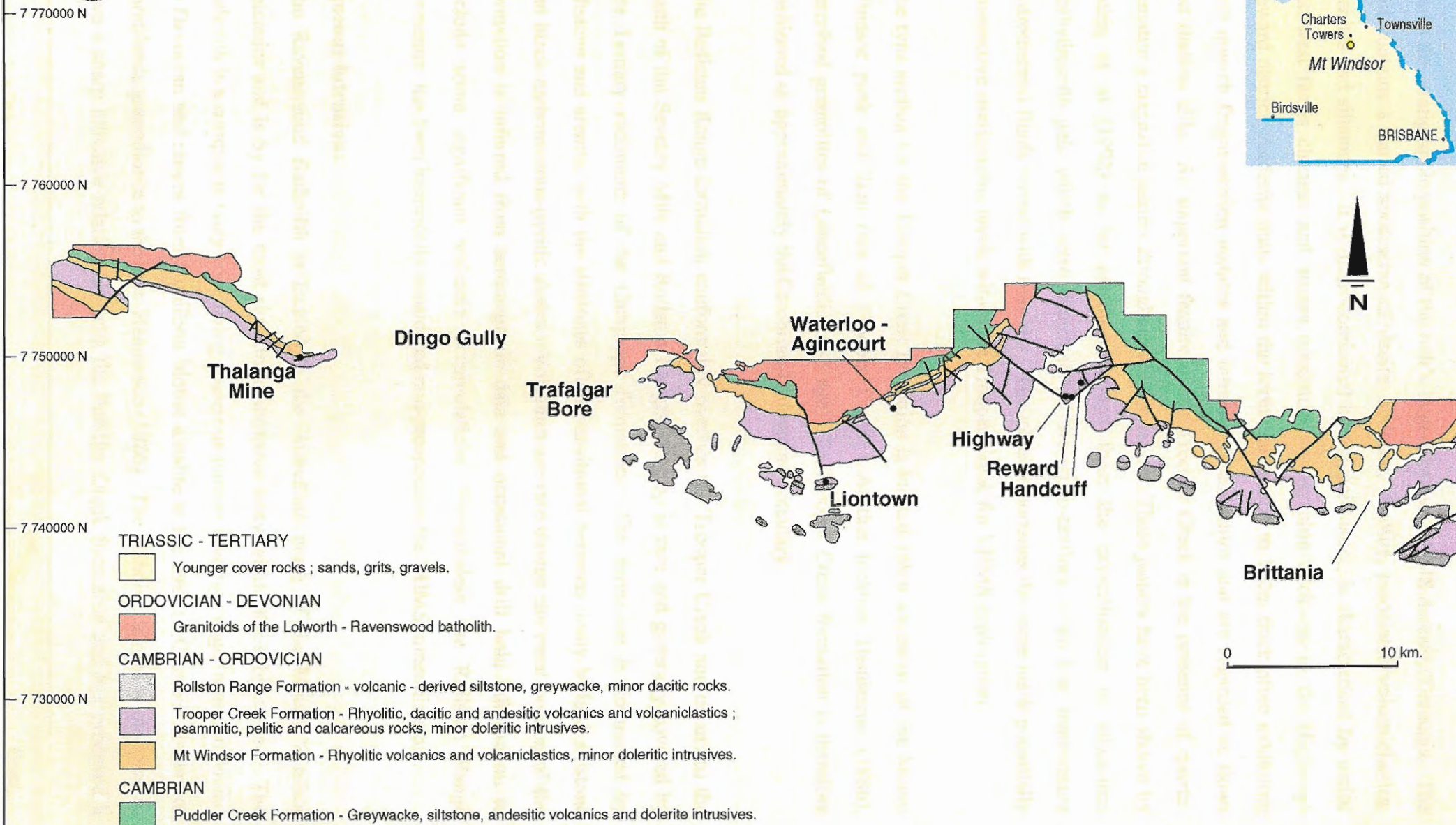
The age of the Mount Windsor subprovince (Seventy Mile Range Group) has been estimated from palaeoantological data. Henderson (1986), reported 25 graptolite localities and assigned a late Cambrian to lower Ordovician age to the subprovince. The following summary of the stratigraphy is adapted from Henderson (1986) and subsequent company exploration data.

The basal unit of the Mount Windsor subprovince is known as the Puddler Creek formation. This formation consists of a monotonous succession of continentally derived fine to medium grained lithic sandstone and greywacke interbedded with siltstone. No fossils have been found in the Puddler Creek formation and it has been assigned to the late Cambrian by Henderson, (1986). There are no known VHMS occurrences within the Puddler Creek formation.

The Mount Windsor volcanics conformably overlie the Puddler Creek and crop out extensively as the core to the Seventy Mile Range between Warrawee and Mount Windsor, and between Thalanga and Waddy's Mill. The Mount Windsor formation comprises rhyolite lavas with varying phenocryst abundances of quartz and albite. The rhyolites may exhibit flow banding and typically occur as lavas, coalesced lava domes and sills. The Mount Windsor volcanics have been assigned a late Cambrian age by Henderson (1986), and can be best distinguished from the overlying rhyolites of the Trooper Creek formation by their immobile element ratios.

The Trooper Creek formation is host to all the known VHMS occurrences in the Mount Windsor subprovince. The Trooper Creek-Mount Windsor interface is conformable and

MT WINDSOR GEOLOGY



marks the stratigraphic position of the belt's largest known VHMS deposit, Thalanga. The unit contains a varied succession of dacite, andesite, rhyolite, associated volcanoclastics, arenites and siltstones. It is often dominated by volcanoclastics, is characterised by major east-west facies changes and attains maximum stratigraphic thickness in the Highway-Reward district. Andesite units within the formation are up to 100m thick often exhibiting both quench fragmentation textures and intrusive relationships and are regarded as flows and shallow sills. An important feature of the Trooper Creek is the presence of quartz-hematite \pm magnetite jaspers throughout the formation. These jaspers have been shown by Duhig et al (1992) to be exhalites formed from the crystallisation of silica-iron oxyhydroxide gels which were deposited on the paleo-seafloor when low temperature hydrothermal fluids mixed with seawater. The exhalite horizons therefore mark potentially prospective stratigraphic levels within the Trooper Creek for VHMS exploration.

The type section for the Trooper Creek formation is located 16km southeast of the Mount Windsor peak and 2km east of Trooper Creek. At this location Henderson (1986), described graptolites of Lancefieldian 2-3 age. The Trooper Creek formation is therefore positioned at approximately the Cambrian-Ordovician boundary.

The Rollston Range formation conformably overlies the Trooper Creek and occurs to the south of the Seventy Mile and Rollston Ranges, outcrop is rare and generally covered by late Tertiary sediments of the Campaspe formation. The formation is dominated by siltstone and arenite, with the siltstones often transitional between thinly bedded siltstone and black carbonaceous-pyritic shales. Volcanics are rare though the basal portion of the formation is inferred from aeromagnetic data and occasional drill hole information to include some significant volcanic accumulations. Nevertheless the Rollston Range formation has been historically considered non-prospective for VHMS mineralisation.

3.2 Igneous Intrusions

The Ravenswood Batholith is located to the immediate north of the Mount Windsor volcanics and is by far the most significant intrusive body within the subprovince. The batholith is a composite body comprising numerous plutons ranging in age from Ordovician to Devonian and ranges from a uniform biotite tonalite to the west of Charters Towers to hornblende granodiorite to the east Henderson (1986). The batholith is readily observed to have a sharp intrusive relationship with the Puddler Creek formation and has produced a

contact metamorphic aureole of up to 0.6km in width comprising schists and hornfels with cordierite-biotite and biotite-muscovite mineral assemblages. In close proximity to the tonalite/granodiorite-Puddler Creek contact, thin pegmatite veins and small apophyses often intrude the sediments and andalusite porphyroblasts are sometimes developed close to the granitoid contact.

3.3 Structure

The Mount Windsor and Trooper Creek formations were deposited in an inferred back arc extensional environment with syn-depositional extensional faults serving as the major fluid focusing pathways towards sites of VHMS deposition (Berry et al, 1991). The early extensional faulting is unrelated to deformation of the stratigraphy though is responsible for rapid lateral changes in thickness of individual stratigraphic units.

Studies by Berry (1991) have identified a multiphase deformational history for the Mount Windsor subprovince;

- D1 An early localised thrusting event (evident in the Mt Surprise area) accompanied by south plunging folding generally associated with moderate to steeply south dipping bedding parallel faults.
- D₂ Regional folding of the Mount Windsor volcanics around E-W axes with the development of a regional cleavage S₂ (Berry, 1991). The entire Seventy Mile Range Group is south dipping and south facing implying a wavelength exceeding 10km. Associated metamorphism peaks at upper greenschist facies.
- D₃ A late faulting event causing relatively small scale disruptions to the stratigraphy. These faults generally have a northeasterly orientation approximating the so called Mount Leyshon trend. At the Truncheon prospect near Highway-Reward a pyrophyllite-topaz-sericite assemblage with an S₃ cleavage is developed along the Truncheon fault (D₃). This association may be related to a Permocarboniferous acid-sulphate-fluoride alteration system (Berry et al, 1991).

3.4 Tectonic Setting

A generally accepted model for the tectonic evolution of the belt, taken from Stolz (1994), is as follows:

- Stage 1** The Proterozoic margin of north-eastern Australia encountered a westerly dipping subduction zone of cold and relatively dense oceanic crust during the early Cambrian.
- Stage 2** Dehydration of the downgoing oceanic crust generated melting in the upper mantle and wedge, which resulted in the onset of continental margin arc volcanism. Remnants of the continental arc have not been identified in the rock record.
- Stage 3** Trench retreat is considered responsible for extension of the arc which in turn caused the development of a back-arc basin.
- Stage 4** During the mid-late Cambrian continued lithospheric thinning caused the extrusion of the small volume of Puddler Creek basalts and andesites and deposition of continentally derived sediments in the back-arc basin. [The mafic rocks are characterised by moderate TiO_2 (+2 wt %), high P_2O_5 (0.6 wt %), high (Zr, Nb, Th and LREE), and low Zr/Nb (Stolz, 1994)]
- Stage 5** In the late Cambrian increased heat flows were generated from the upward migration of mantle related to the modification of the downgoing slab, and caused melting of the continental crust which eventually erupted as the Mount Windsor rhyolite. [The Mount Windsor rhyolite can be discriminated from the Trooper Creek by the lower Ti/Zr and P/Zr values, higher Th and REE concentrations (Stolz, 1994). Of relevance to the REE research in this thesis, Stolz found that the Mount Windsor rhyolites typically have a distinct negative Europium anomaly that is rare or weakly developed in Trooper Creek dacites.]
- Stage 6** At the onset of the Ordovician, subduction-modified mantle began to erupt at the surface giving rise to the volcanics of the Trooper Creek Formation (TCF). [The rhyolites and dacites of the TCF are characterised by higher Ti/Zr. Mt

Windsor formation rhyolites have Ti/Zr in the range 2-7 and Trooper Creek formation rhyolites vary between 7 and 12]

Stage 7 Following deposition of the Trooper Creek, volcanism began to decline, crustal extension and growth fault activity ceased. This gave rise to the fill stage of basin development and deposition of the Rollston Range Formation.

4.0 DISCOVERY AND EARLY HISTORY

The Carrington Goldfield as it was originally known was discovered in 1905 by William Frederick Carrington while searching for his horses, Lion and Noble. The Carrington Au-Cu ore was situated within the Liontown footwall stringer zone, and was eventually worked over a strike of 920 feet to a depth of 676 feet. During the period 1905-11 the ore bodies were mined for a meagre 28,126 ounces of gold bullion (Levingston, 1972). The bulk of the economic production came from the oxide, carbonate and supergene zones above the water table. As was the case with many of the small mining operations at the turn of the century, production became difficult when the water table was reached and the hypogene ore became less attractive. Although the Lion PC shaft was eventually deepened to 200 metres vertical depth, well into the sulphide zone, the workings and adjacent town were abandoned in 1911 (Levingston, 1972).

In 1951 Parsons and Jansen discovered the "silver-lead" lodes, and from 1951-61 some 9,285 tons of ore was treated yielding 2,990 ounces of gold, 53,957 ounces of silver, and 520 tonnes of lead (Levingston, 1972). The silver-lead lodes have since been redefined by Pancontinental Mining Limited and are now referred to as the Carrington lode.

Modern exploration activity commenced at Liontown in 1953 when Broken Hill South Ltd (BHS) was attracted to the prospect by a state geological survey report outlining the potential for the continuation of the silver-lead lodes to the east. BHS completed three exploratory diamond holes though did not gain significant encouragement to maintain their exploration effort.

The period 1953-61 saw a series of experimental EM surveys undertaken by the Bureau of Mineral Resources at Liontown and at a nearby prospect known as Tigertown. Numerous 'anomalous responses' were recorded though subsequent drill testing in 1960-61 by the Queensland Geological Survey showed none to be related to massive sulphide mineralisation. The State Survey also drilled twelve holes at Liontown to "test the ground ahead of the Liontown and New Queen silver-lead lodes".

Activity at Liontown in the 1960's appears to have been restricted to small scale prospecting. In the early 1970's exploration activity was reawakened by a small local company, Nickel Mines Ltd. Nickel Mines drilled 60 relatively shallow diamond holes in the immediate Liontown area. The drilling was focused on the Carrington lode and generally at a set target depth of 80m. Assaying was carried out at Assay Laboratories Pty Ltd in Sydney and all gold assays reported in ounces per ton. Re-assaying of the core by Newmont has since shown that gold assays were exaggerated by a factor of up to 10x.

- Records of the Nickel Mines drilling are poor with much of the exploration undocumented.

In 1983-84 Esso Exploration and Production Aust Inc joint ventured into the prospect and carried out well managed exploration at Liontown and on the peripheral prospects covered by the Liontown project mining leases. Esso successfully defined the three stratiform lead-zinc lodes within the Liontown Horizon. In late 1984, Esso management arrived at the conclusion that the host stratigraphy was dominated by shallow water facies and was unlikely to have been conducive for the formation of a large (>10Mt) VHMS orebody. In late 1984 - early 1985 Esso withdrew from the joint venture (Maclean, 1985).

The period 1987-90 saw a series of shallow percussion drilling programmes carried out by Great Mines Ltd in an attempt to define an oxide-supergene gold resource over the up-dip weathered portions of the Carrington lode and adjacent stringer system. Although numerous high grade intercepts were returned, the overall nature of the mineralisation was erratic and defied definition as a coherent resource.

During the period 1 January 1994 to 31 July 1995 Pancontinental carried out an extensive exploration program to further define the existing base metal mineralisation at Liontown and to discover additional resources in the immediate area. To this effect detailed 1: 5000

scale mapping was undertaken throughout the area covered by the mining leases and eleven diamond holes and 101 reverse circulation drillholes were completed.

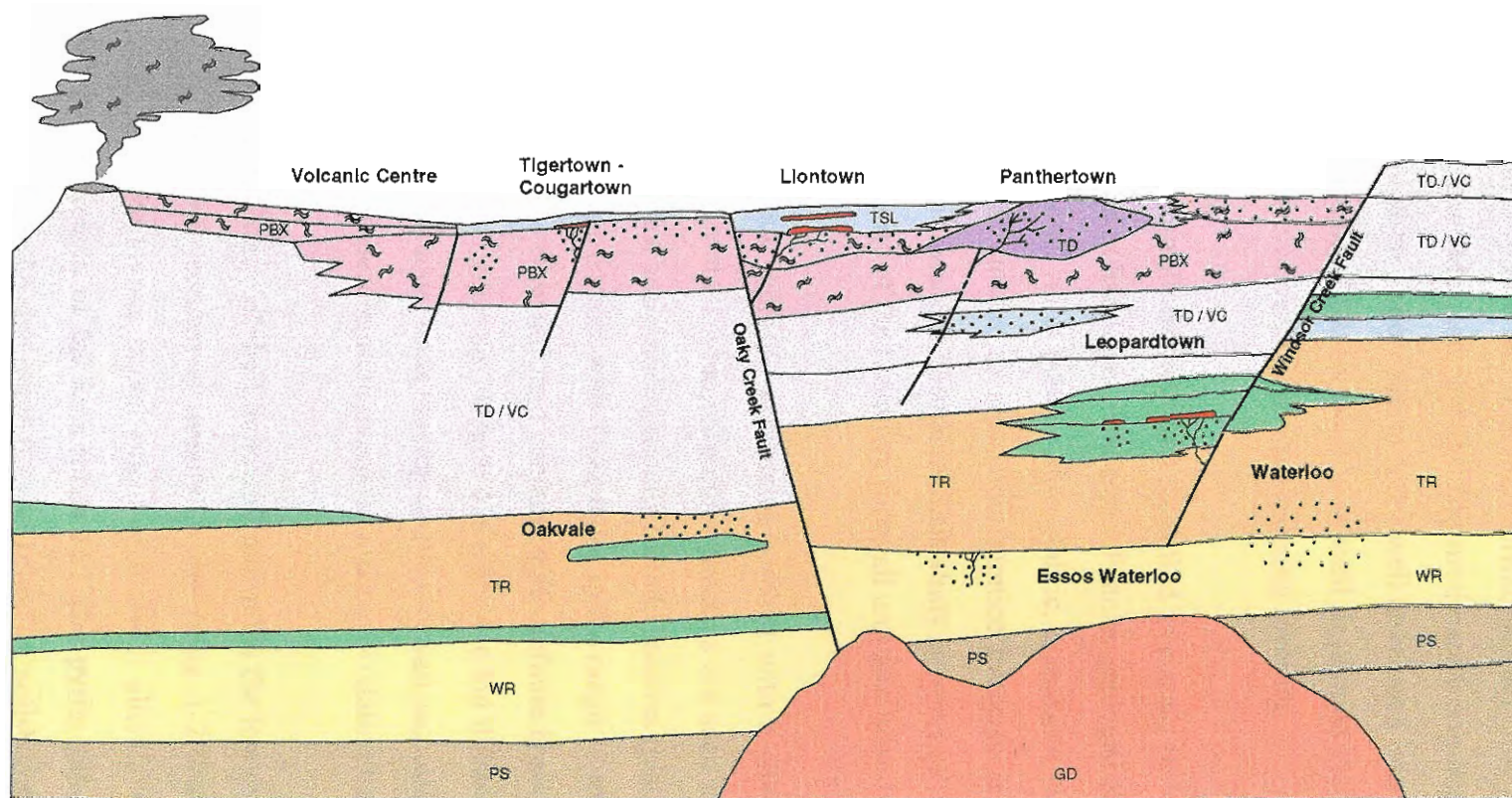
5.0 GEOLOGY OF THE LIONTOWN DEPOSIT

The Liontown-Tigertown-Leopards town district for the purposes of this study, has been restricted to the 37.8km² area covered by the mining leases. The greater Liontown district (plate 1, in pocket) is unique in that this is the only portion of the Seventy Mile Range Group with significant VHMS mineralisation at the base, centre, and top of the Trooper Creek formation. These are Esso's Waterloo (Mt Windsor formation - Trooper Creek interface), Waterloo (central Trooper Creek formation) and Liontown (top of the Trooper Creek formation). All these occurrences are within a restricted portion of the Trooper Creek formation that has a stratigraphic thickness of 2km and a strike length of 6.5km (Figure 3).

- Outcrop throughout the project area is relatively sparse with low-lying isolated hills at Liontown, Tigertown and Leopards town providing the majority of exposures. The terrain intervening is typically blanketed by flat lying clays and unconsolidated quartz-rich sands and gravels of the Campaspe formation. The sediments of the Campaspe formation are essentially alluvial valley fill laid down during the Pliocene period and are estimated to occupy an area exceeding 8000km² in the Charters Towers - Pentland region.

The Liontown-Tigertown-Leopards town district is situated on a major south facing bend in the Seventy Mile Range Group (convex south). The Liontown deposit occurs at and below the contact of a silica-sericite-pyrite altered dacitic pumice breccia unit and an overlying sericitic-pyritic siltstone. In ascending order the upper stratigraphy consists of arenites, chert, bedded siltstone-arenite, carbonaceous and pyritic black shale, feldspar phyric dacite and siltstone. The Liontown deposit is the main known focus of mineralisation with an estimated metal content of 1.8Mt @ 6.16% Zn, 2.2% Pb, 0.48% Cu, 0.9g/t Au and 29g/t Ag (Miller et al, 1995). The following chapter documents the stratigraphy, mineralisation and structure of the Liontown deposit.

LIONTOWN DISTRICT - DIAGRAMMATIC SECTION



ORDOVICIAN - DEVONIAN

GD Granitoids of the Lolworth - Ravenswood Batholith.

ORDOVICIAN

Trooper Creek Formation

TSL Siltstone, sandstone and dacitic volcanics.

TD/VC Dacite and dacitic volcanics.

PBX Dacitic Pumice Breccia.

TD Dacite.

TR Rhyolite, Rhyolitic Volcanics.

TA Andesite, siltstone, Andesitic Volcanics.

CAMBRIAN

Mount Windsor Formation

WR Rhyolite lavas, volcanics, minor dolerite intrusives.

Puddle Creek Formation

PS Greywacke, siltstones, andesitic volcanics and dolerite intrusives.

Pyrite ± sericite alteration.

Volcanogenic Massive Sulphide.

5.1 Stratigraphy and Lithogeochemistry (In Ascending Order)

5.1.1 Footwall Pumiceous Mass Flow Unit/s

The footwall pumice breccia is located stratigraphically below the Liontown Horizon and has been historically referred to as the footwall schist (Levingston, 1972) and the footwall pyroclastics-dacite (Maclean, 1985). The stratigraphy consistently dips at 70° to the south, has a strong foliation \pm shear fabric and a well developed intersection lineation (moderately eastwards). In general the foliation is so well developed that it and silica-sericite-chlorite alteration completely overprint any pre-existing layering.

The Liontown footwall unit was first identified as a mass-flow pumice breccia on the basis of features visible at hand-specimen scale. Pancon geologist R. Sainty reported that the unit contained occasional relict pumice shred fabric, a massive character typical of mass-flow deposits, and was similar to mass-flow pumice breccias at the Rosebery and Hercules VHMS deposits in western Tasmania. This study presents strong thin section evidence that confirms the identity of the Liontown footwall unit as a mass-flow pumice breccia.

In outcrop the rock typically appears as a schist with a characteristic nobbly fine augen texture. In drillcore the Liontown pumice breccias are seen to comprise domains of white augen textured silica and chlorite-sericite lenticle features (plates 2-3). Geochemically, the pumice breccias are dacitic, with Ti/Zr ratios in the range 12 to 17. The pumice breccia unit is a multiple mass flow unit and contains quite definite breaks between flow units marked by thin siltstone-ash intervals. Figure 4 is a graphic log illustrating the nature and thickness of some of the individual units making up the footwall succession. Unfortunately, structural complications and the alteration overprint makes correlation between drillholes impractical.

A characteristic feature of the Liontown Footwall is the low overall content of disseminated pyrite. The pyrite content is usually in the range 1-2% at Liontown and shows little variation over the known lateral extent of footwall alteration from Tigertown through to Orion, a strike length of 6.7 kms (plate 1). The pyrite generally occurs as disseminated euhedral crystals in the size range 0.25 to 1mm. In polished thin section the pyrite crystals

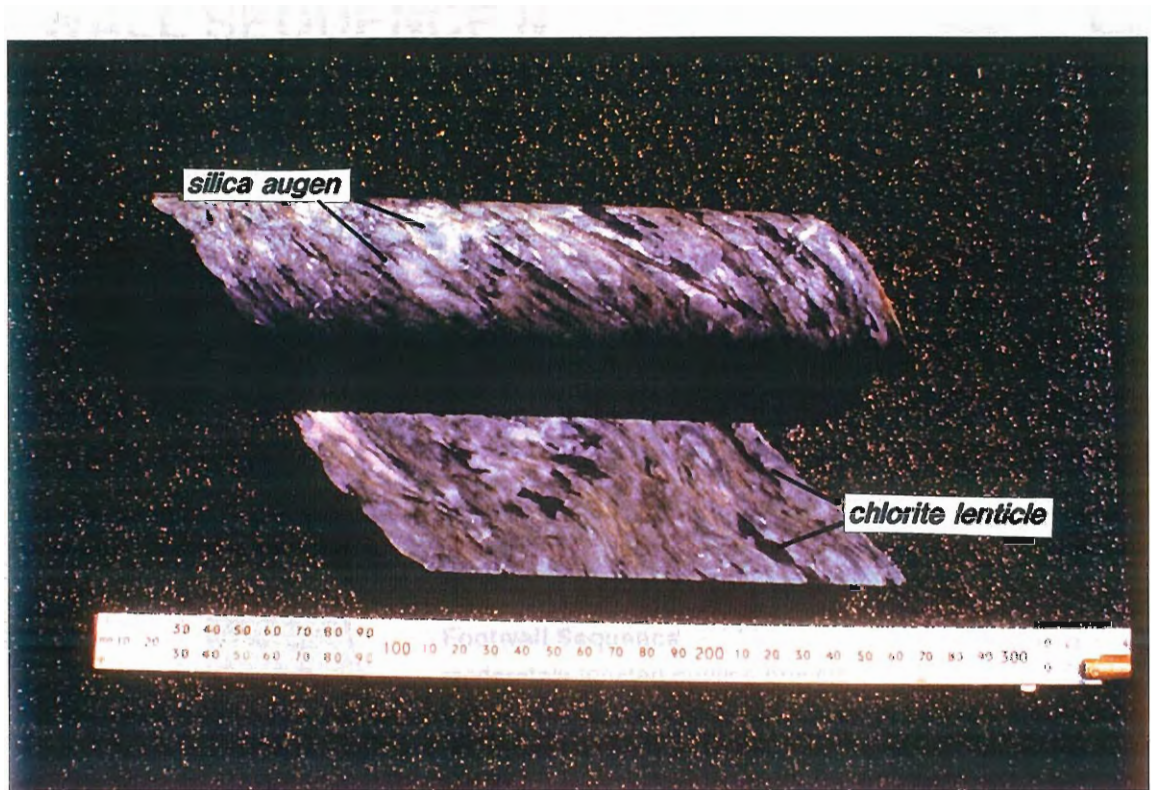


Plate 2: Lione town: silica augen-chloritic lenticle textured pumice breccia. Black domains = chlorite and White domains = hydrothermal silica. Drillhole LLD 128 - 394.4m

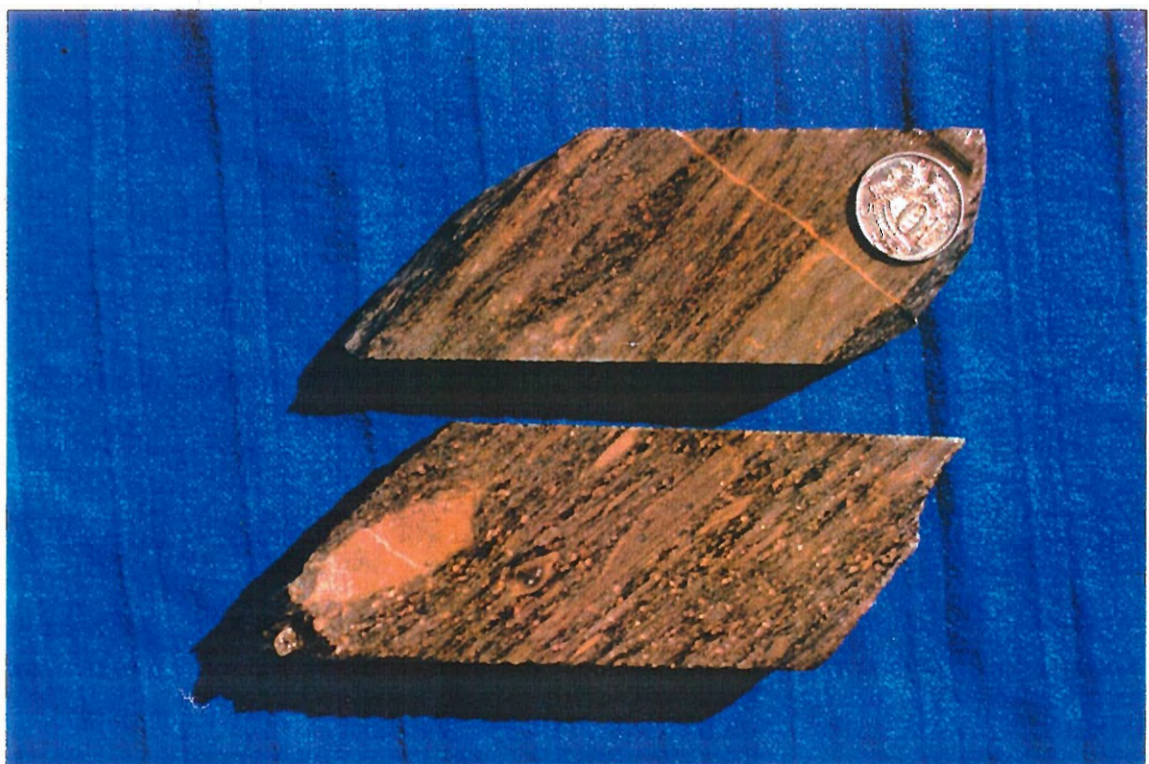
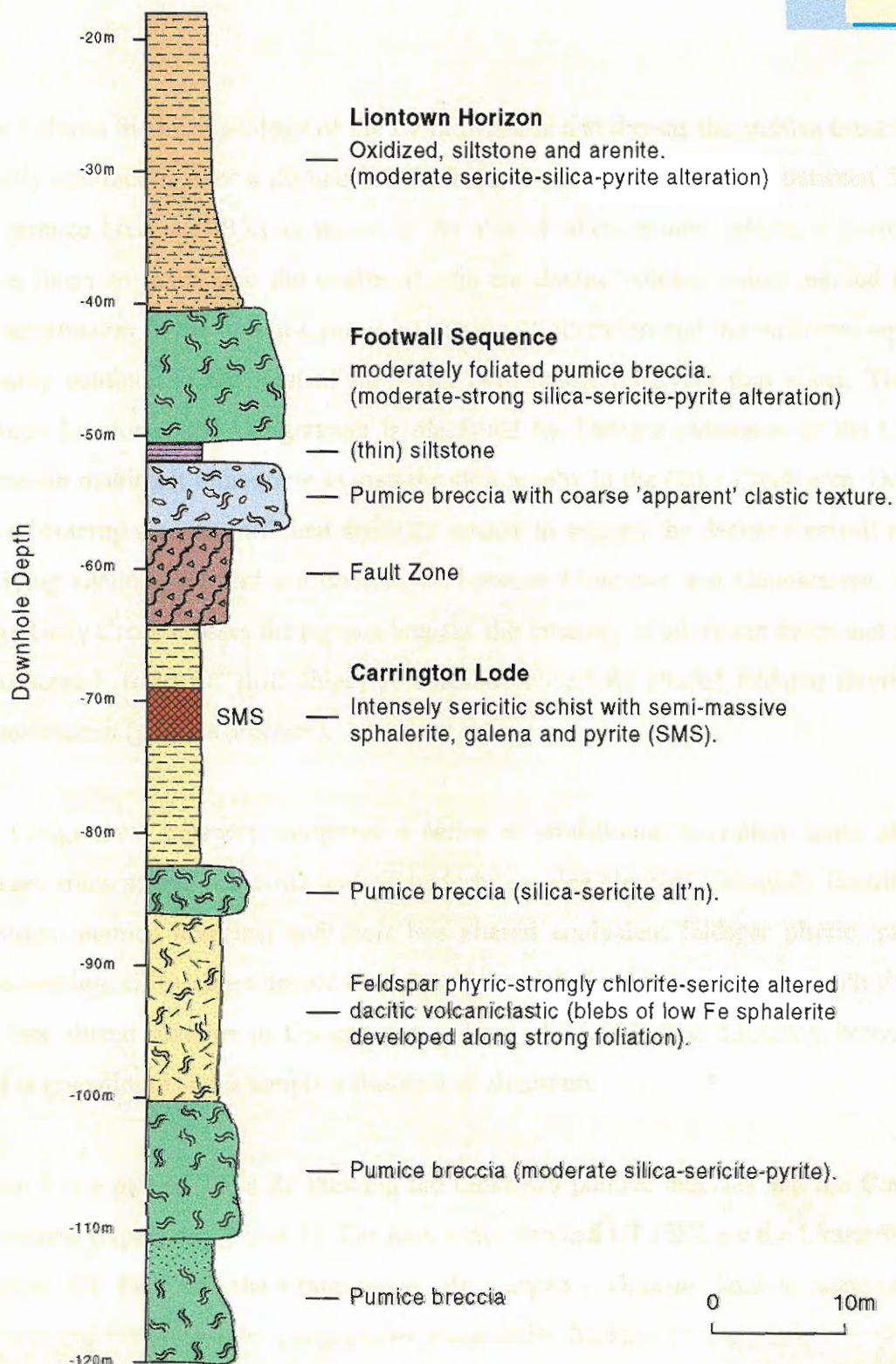


Plate 3: Panthertown - strongly foliated and sericitic, lithic bearing, feldspar phyric pumice beccia. Drillhole LLD 138 - 310m.

DRILLHOLE LLD132 FOOTWALL SEQUENCE & CARRINGTON LODGE



routinely display overgrowths with at least three generations recognised. It was intended to document the along strike variation in δS^{34} of pyrite and double sided polished (130mm) thin sections were prepared for this purpose. However technical difficulties with the laser ablation unit at the University of Tasmania and resultant sample queues terminated the investigation.

Plate 1 shows the local geology of the Liontown area and depicts the pumice breccia unit as laterally continuous over a distance of 6 kms and varying in thickness between 50-700m. The pumice breccia (PBX) as shown is the altered silica-sericite-chlorite \pm pyrite variety and is likely to grade into the unaltered adjacent dacitic volcanoclastics marked (TDVC). The termination of the unit at Lynx is a function of alteration and the unaltered equivalents probably continue to the west of the Lynx fault below relatively thin cover. The terrain between Liontown and Cougartown is blanketed by Tertiary sediments of the Campaspe Formation making it impossible to map the stratigraphy in the Oaky Creek area. Despite the lack of outcrop there is sufficient drillhole density to suggest the dacitic footwall rocks and overlying siltstone-arenites are continuous between Liontown and Cougartown. At about where Oaky Creek crosses the pumice breccia, the intensity of alteration drops and the rocks are observed (from RC drill chips) as silica-albite-sericite altered feldspar phyric dacitic volcanoclastics (pumice breccias).

The Cougartown prospect comprises a series of stratabound alteration zones alternating between silica augen - chloritic lenticle textured pumice breccias (texturally identical to the Liontown pumice breccias) and their less altered equivalent feldspar phyric, pumiceous lithic-bearing, silica-albite dacitic breccias. Plates 4-5 show the textures of both the altered and less altered variants in Cougartown drillhole CGD001. The boundary between these units is gradational and is simply a function of alteration.

Figure 5 is a plot of Ti vs Zr showing the Liontown pumice breccias and the Cougartown equivalents (Appendix, Table 1). The data series denoted LT PBX are the Liontown pumice breccias, CT PBX are the Cougartown silica augen - chloritic lenticle textured pumice breccias and CT PBXf the Cougartown silica-albite feldspar phyric pumice breccias. The most altered lithologies LT PBX and CT PBX show a strong linear correlation. This correlation in effect defines an alteration line for the dacitic pumice breccias. The less

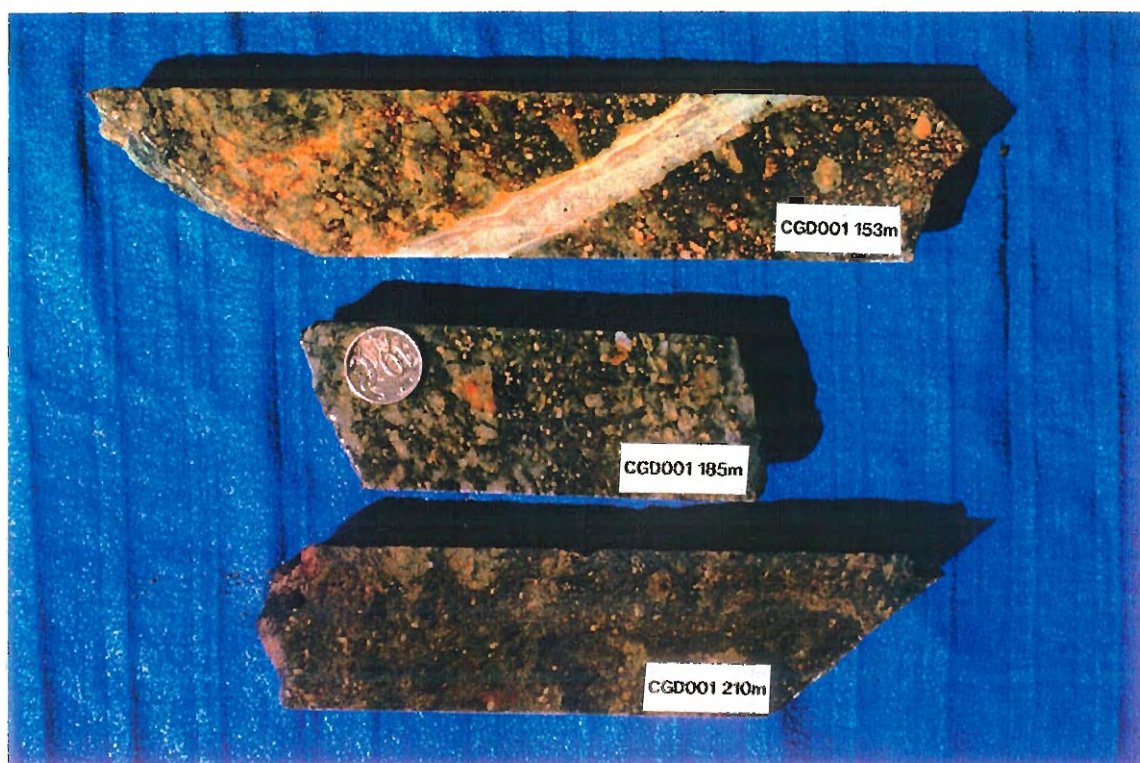


Plate 4: Cougartown - weak to moderately silica-albite-chlorite altered feldspar phyric pumice breccias. Pink colouration is exaggerated by photocopy colour limitations.



Plate 5: Cougartown - Strongly silica-sericite-chlorite altered pumice breccia displaying well developed silica augen - chloritic lenticle texture. Texturally identical to Liontown pumice breccia.

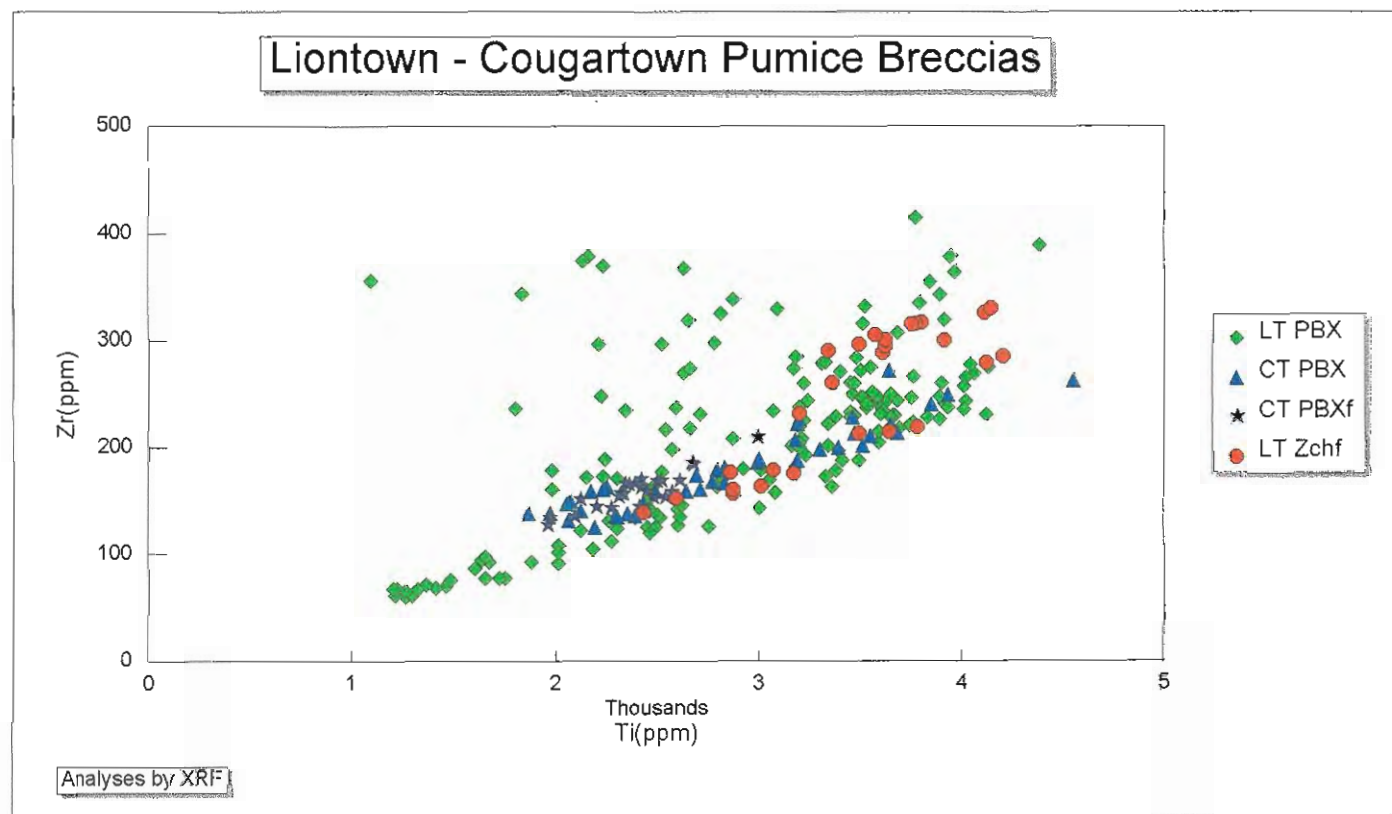


Figure 5: Liontown and Cougartown Ti vs Zr plot showing the various pumice breccias and the feldspar-chlorite schist below the Carrington lode (LT Zchf).

altered CT PBXf series plots near the middle of this line, samples plotting along the line between the CT PBXf grouping and the origin have experienced intense silica alteration and overall mass gain whereas those samples plotting with higher Ti, Zr concentrations (away from the origin) are characterised by more dominant sericite-chlorite alteration and overall mass loss. In terms of immobile element geochemistry the Liontown and Cougartown pumice breccias are remarkably similar.

Given the immobile element chemistry is very similar and the Cougartown pumice breccias with the strong silica alteration over print appear texturally identical to the Liontown pumice breccia (Plate 2), there is a strong possibility they both have the same protolith. At Cougartown there are domains within the pumice breccia sequence where the alteration is sufficiently subdued to allow recognition of primary textural features. These features are best observed in thin section and include clusters of broken feldspar crystals, glass shards, lithic fragments and tube pumice. Plate 6 shows a section through a pumice tube perpendicular to the long axis adjacent to a cluster of feldspar crystals and glass shards. Plate 7 shows a section through tube pumice parallel to the long axis of the pumice tubes. These features are good evidence that the protolith is indeed a pumice breccia. Recent drilling at Panthertown, located 3kms to the east of Liontown has revealed similar lithic bearing pumice breccias (Plate 3) to those observed at Cougartown which further augments the proposal that the intervening pumice breccias at Liontown are indeed true pumice breccias.

It remains equivocal as to whether or not the chloritic lenticle features in the pumice breccias are chlorite replaced pumice fragments or independent domains of chlorite alteration. At Cougartown the pumice fragments as shown in Plates 6 and 7 are non chloritic.

Another unit within the Liontown footwall sequence that has been the subject of discussion by numerous geologists is the '**black chloritic, feldspar phyric schist**' situated stratigraphically below the Carrington lode. Esso geologists referred to the unit as the footwall dacite and interpreted it as a 'mushroom' shaped dacitic subvolcanic intrusion thought to have localised the hydrothermal fluids responsible for deposition of the Carrington Lode.

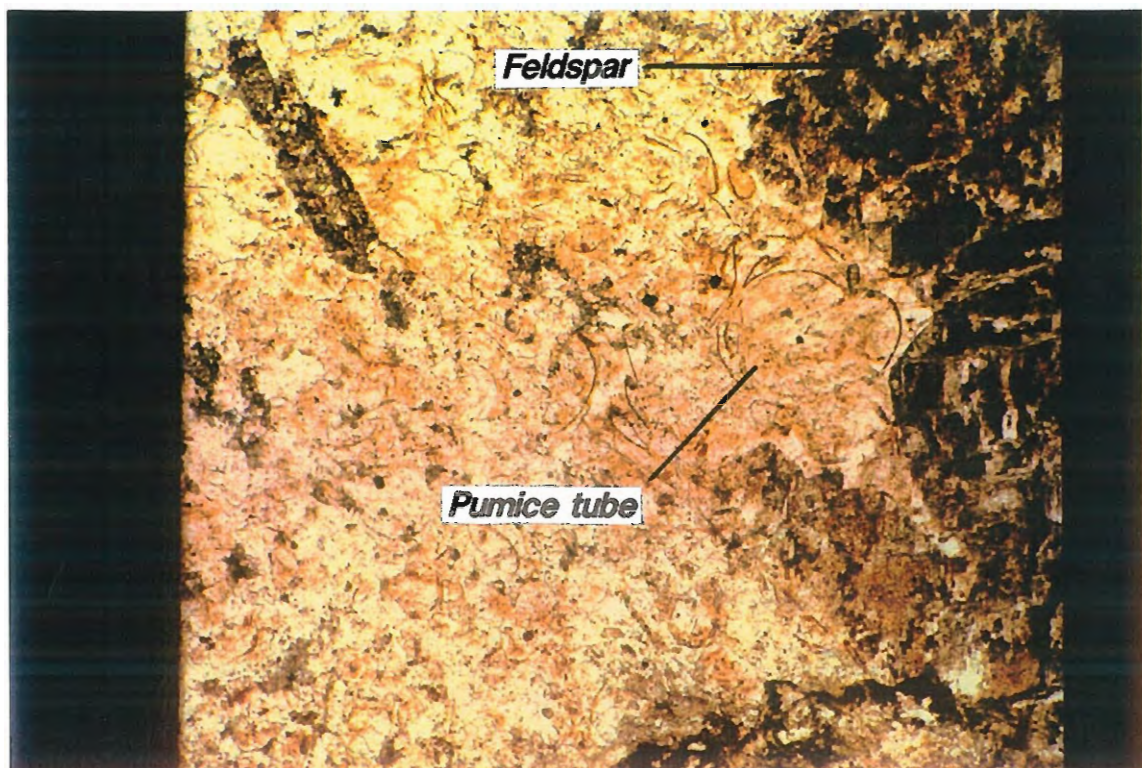


Plate 6: Cougartown: Photomicrograph, plane transmitted light (PTL). Section through tube pumice cut perpendicular to long axis of pumice tube. Drillhole CGD001-150.5m.
Scale 1cm = 500 microns.



Plate 7: Cougartown: Photomicrograph (PTL): Section through pumice fragment (top RH quadrant) cut parallel to long axis of pumice tubes. Drillhole CGD001 - 150.5m.
Scale 1cm = 750 microns.

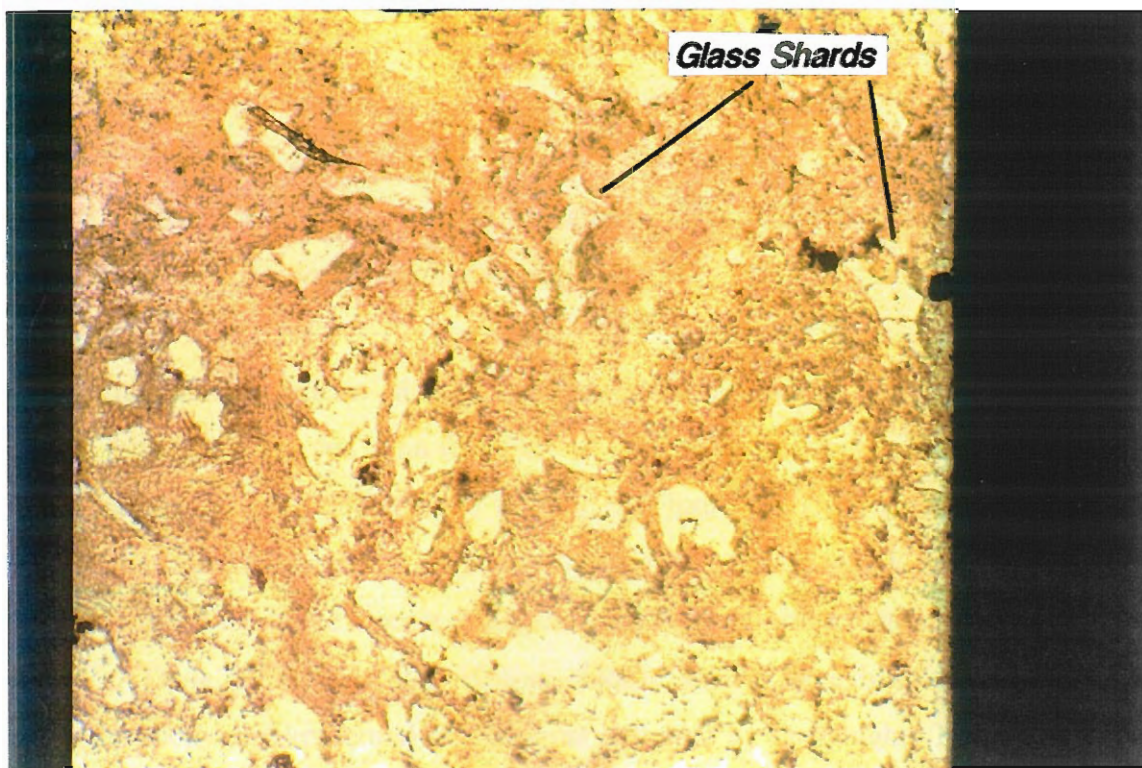
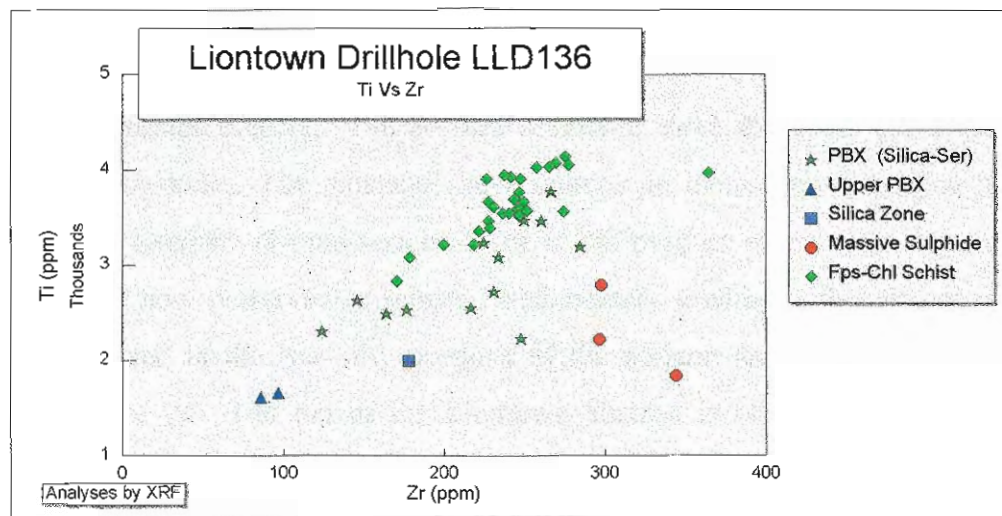


Plate 8: Lione town: Photomicrograph (PTL): Relict glass shards in feldspar-chlorite schist below the Carrington Lode. Drillhole LLD132-87m Scale 1cm = 500 microns.

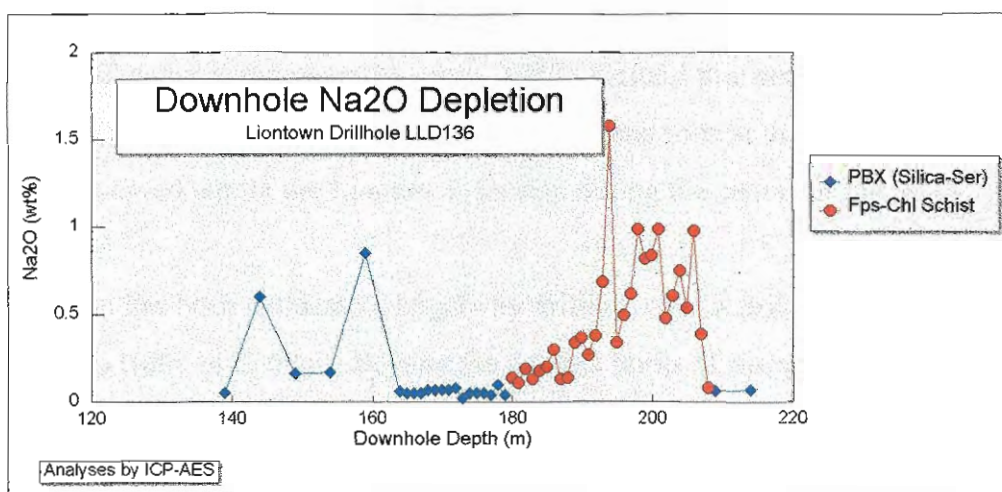
Investigation of the unit as part of the current study has revealed the presence of lithic clasts and relict glass shards (Plate 8). Re-logging of key diamond holes (LLD101-103) has also shown that the geometry of the unit is not 'mushroom like' but in fact lenticular and stratiform. These features have led to the unit being re-interpreted as a stratiform dacitic mass flow unit within the overall pumice breccia sequence. It is difficult to determine if the unit was originally significantly different to the enclosing pumice breccias. The presence of glass shards and the unit's proximity to thin siltstone/ash intervals may suggest it was perhaps less pumiceous and possibly consisted of feldspar and a finer matrix of ash and silt. Certainly it has been left with a distinctive alteration assemblage comprising black chlorite and sericite, silica alteration is notably absent.

Visually the chlorite-sericite alteration appears intense though surprisingly there are abundant feldspars preserved. The feldspars have retained their crystal shape though have suffered varying degrees of alteration to sericite. Figure 6 shows a downhole profile of Na_2O and the alteration index $\text{AI} = [(\text{MgO} + \text{K}_2\text{O}) / (\text{Na}_2\text{O} + \text{CaO} + \text{MgO} + \text{K}_2\text{O}) \times 100]$ (Ishikawa et al, 1976) through pumice breccia (PBX) and feldspar-chlorite schist in drillhole LLD136 (Appendix, Table 2). Clearly the feldspar-chlorite schists have been more resistant to feldspar destructive hydrothermal alteration as indicated by their higher Na_2O content and lower AI values. At Liontown total feldspar destructive alteration is characterised by the presence of intense silica flooding, that is the silica augen-chloritic lenticle texture. The feldspar-chlorite schists appear to have been armoured against pervasive silica alteration. The resistance to silica flooding may be due to a primary permeability contrast between highly porous pumice rich breccias and the less porous, finer grained ashy, feldspar phyric unit now preserved as the black chlorite-feldspar schist.

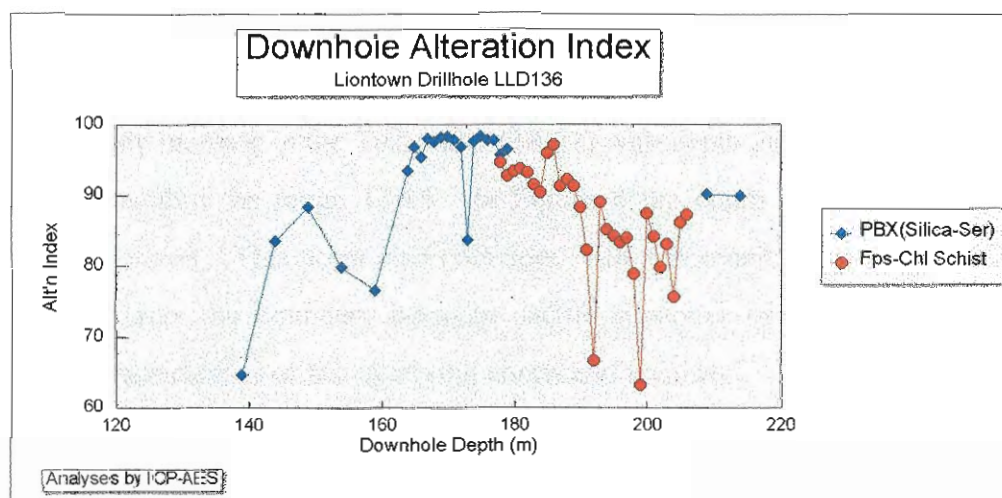
Mg-rich chlorites tend to be dark green to black and are a distinctive alteration feature of many VHMS systems, particularly in the Abitibi belt in Canada. Minor Mg-chlorite zones are also present at Hellyer in Western Tasmania. These Mg-chlorite alteration zones are commonly interpreted as a product of mixing a Si-rich hydrothermal fluid with Mg-rich seawater. If this is also the case at Liontown then the black chlorite below the Carrington lode may map out a similar seawater-hydrothermal fluid mixing zone within the volcanoclastic pile.



[a]



[b]



[c]

$$\text{Alteration Index} = \frac{\text{MgO} + \text{K}_2\text{O} \times 100}{\text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO}}$$

Figure 6: Liontown Footwall - Na₂O% and Alteration Index Profiles
PBX = Pumice Breccia, Fps-Chl = Feldspar-chlorite Schist

5.1.2 Liontown Horizon - Sericitic Siltstone

The Liontown Horizon is a succession of sericitic siltstones and arenites that conformably overlie the pumice breccia. The horizon is host to three sheet-like barite-carbonate-base metal sulphide lodes. The siltstones have undergone intense sericite-silica hydrothermal alteration or alternatively the sericite-silica is the product of exhaled clay minerals. The siltstones are now preserved as schists. Sedimentary grading, although not common, has been recognised in the less silty portions of the horizon and exhibits a consistent south facing (Figure 7). The top of the Liontown horizon is often defined by a 1-2m thick carbonaceous black shale.

Previous workers have referred to the sericitic siltstones of the Liontown Horizon as having a strong tuffaceous component (Maclean, 1985). Careful thin section examination of several samples found no evidence for an ash component and indeed there have been no tuffaceous textures observed within the Liontown Horizon during the course of this study.

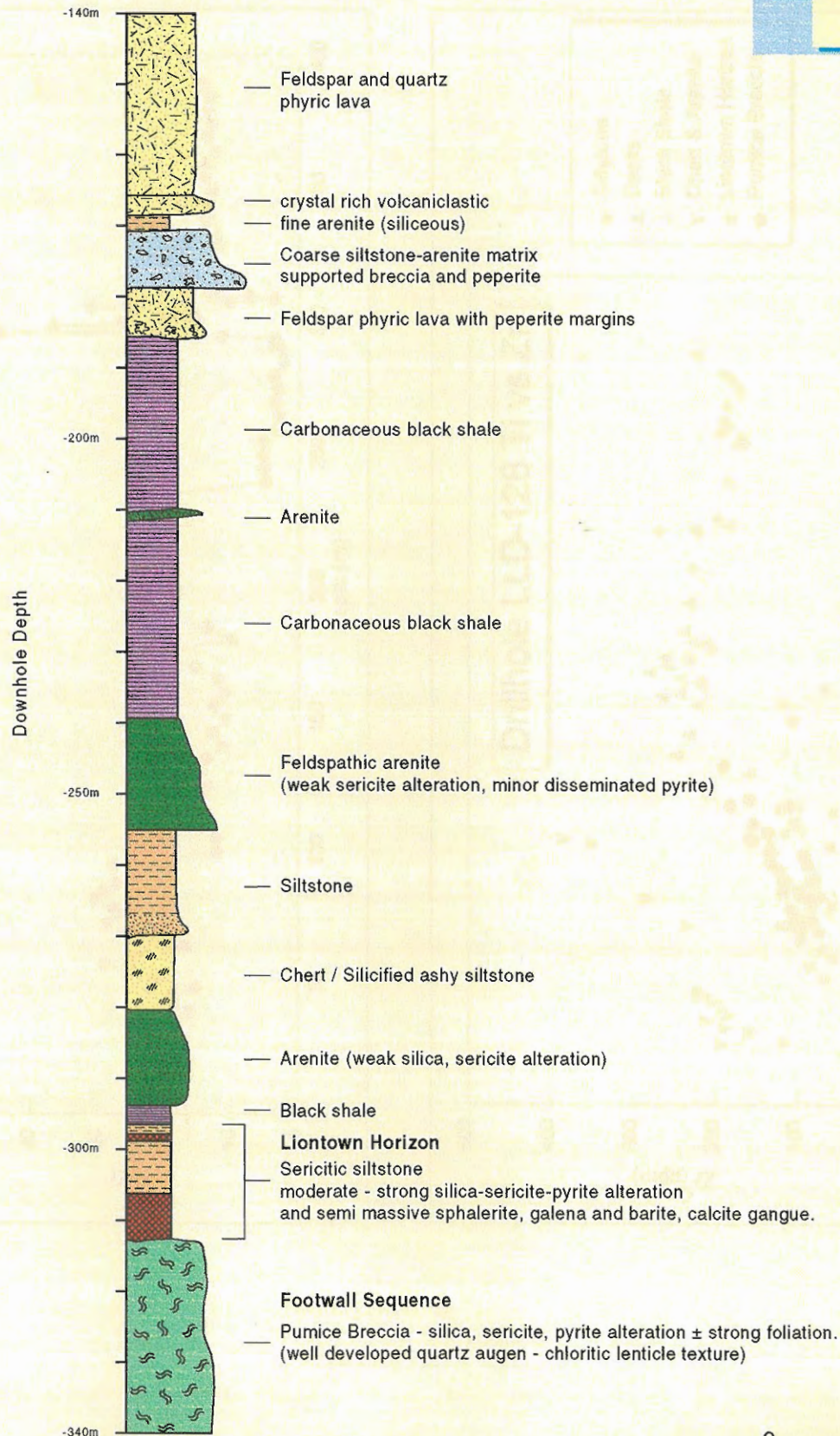
The horizon has been delineated, largely by drilling, over a strike length of 2kms and varies in thickness from 14 to 60m. Beyond the defined limits of the sericitic siltstone the horizon interfingers with coarser grained dacitic and andesitic volcanoclastics.

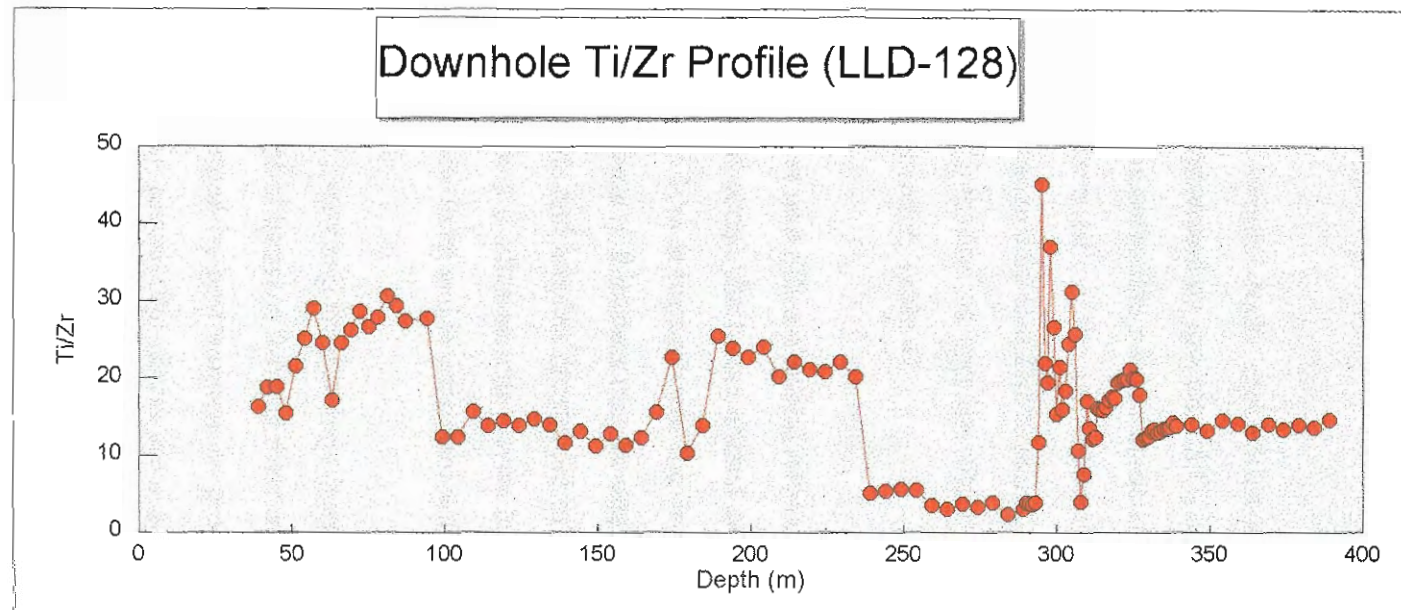
The Ti/Zr ratio of the horizon is characteristically erratic in the range 5-50. Figure 8 illustrates the erratic signature of the horizon in the downhole depth range 292-312m (Appendix, Table 3). The first 15m of pumice-breccia immediately below the horizon shows a steady increase in the Ti/Zr ratio (18-21) with depth and then flattens off remaining consistently within the range 13-15. In Figure 8 the depth 292m marks the top of the Liontown Horizon. This point also coincides with a dramatic drop in the Ti/Zr ratio and essentially marks the boundary between dacitic siltstones of the Liontown Horizon and rhyolitic volcanoclastics of the overlying cherts and arenites.

The rhyolitic volcanoclastics have Ti/Zr ratios in the range 2-6 which are surprisingly low for rhyolite derived volcanoclastics of the Trooper Creek Formation. The values seem to fit best within the range of 2-7 for the Mount Windsor Rhyolite (Sainty, pers com).

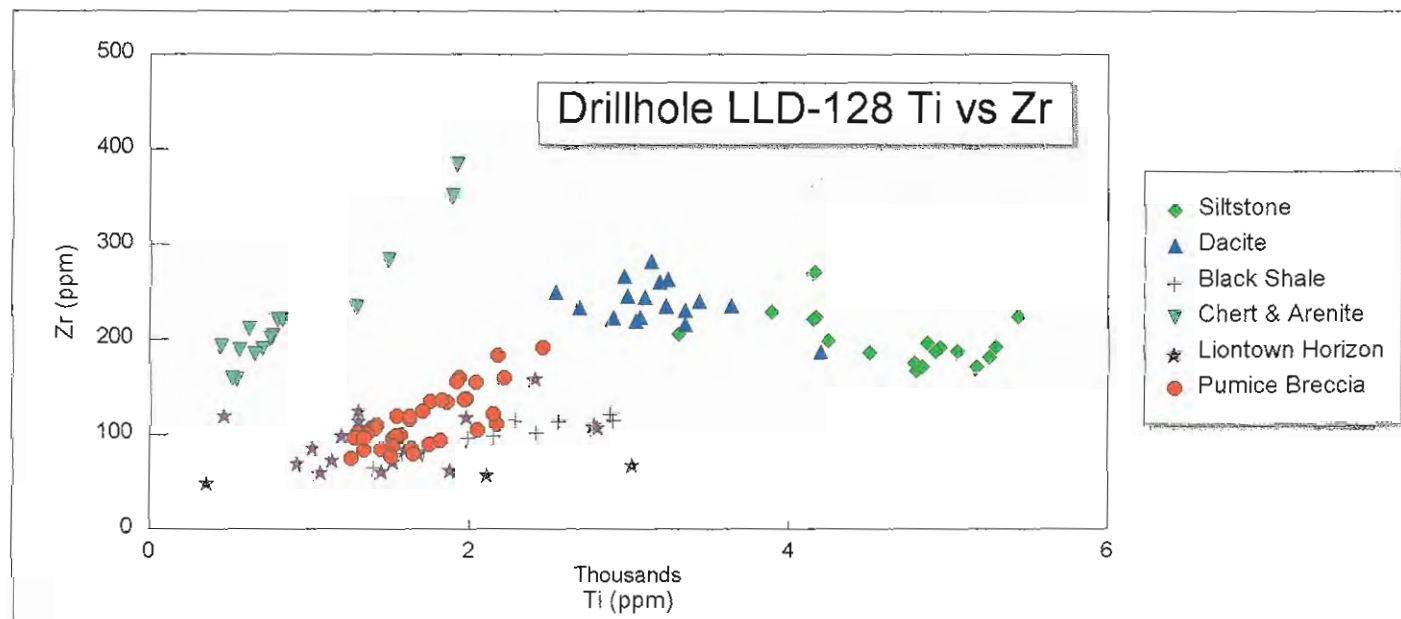
These observations suggest the Liontown Horizon exhalative mineralisation occurs at the boundary between dacitic and rhyolitic volcanoclastics and may by inference, be temporally

DRILLHOLE LLD128 LIONTOWN HORIZON - GRAPHIC LOG STRATIFORM MINERALISATION





[a]



[b]

Figure 8: Lontown Stratigraphy - Ti,Zr Plots

related to a change from dacitic to rhyolitic Trooper Creek volcanism characterised by low Ti/Zr ratios. Alternatively, the cherts and arenites, with the low Ti/Zr ratios may be derived from the erosion and subsequent deposition of Mount Windsor Rhyolite exposed during the later stages of Trooper Creek formation development. Given the current understanding of the geology of Liontown district the source would have to have been located at great distance to the Liontown depocentre (>10 km). The former proposal is preferred.

The whole rock geochemistry of the mineralised Liontown Horizon siltstones is characterised by low total SiO₂ in the range 5.69 to 29.60 wt %, the low silica zones have a strong carbonate ± barite association with CaO up to 41.10 wt %, the higher silica zones are characteristic of the upper barite-chert ± base metal sulphide lode. Na₂O is typically low, in the range 0.05 to 0.2wt % and K₂O is generally in the range 0.50 to 2.58wt % depending on the intensity of sericite alteration and carbonate - base metal sulphide development (Appendix, Table 4).

5.1.3 Chert and Silica-Sericite Altered Arenite

Interbedded cherts and altered arenites overlie the Liontown Horizon and vary in thickness from 30m at the centre of the deposit (10,000E) to 120m on the eastern margin. The abrupt increase in thickness may be due to a synsedimentary growth fault on section 10500E. The cherts and arenites are devoid of base metal mineralisation though have been subjected to a moderate silica-sericite±pyrite hydrothermal overprint. Upwards fining is observed in the arenite units and is consistent with a south younging.

The cherts and arenites have been grouped together due to their remarkably consistent Ti/Zr ratios of between 2-6 and their common silica alteration. The cherts have historically been regarded by past workers as possible silica exhalites capping the Liontown Horizon. This study reveals the cherts are simply silicified laminated-bedded siltstones. The absolute abundances of Ti and Zr as shown in Figure 8 are relatively high, certainly far in excess of the low levels expected of an exhalite produced by the exhalation of hydrothermal fluids on to the seafloor.

The hanging wall cherts and arenites have anomalously low base metal contents. Zinc seldom exceeds 30ppm, Pb 25ppm and Cu rarely exceeds the 6ppm level. In fact these

levels are lower than those of any other stratigraphic unit at Liontown. Barium is anomalous and routinely returns values exceeding 3000ppm.

In thin section the cherts consist of cryptocrystalline silica with no relict volcanic textures observed. The arenites exhibit relict glass shard textures (Plates 9-10). The shards are typically in the size range 50-100µm and vary from cusped to flattened and have been altered to quartz and sericite. Circular volcanic quartz crystals with corroded rims are rare and broken sericitised feldspar crystals with ragged margins are relatively common. These observations suggest the arenites and possibly the cherts include a significant pyroclastic ash component. The thin section observations also show the arenites are not mature sediments, which is at odds with the proposal in section 5.1.3, that they may have been derived from distal Mount Windsor Rhyolite. The identification of a relatively well preserved ash component implies the chert-arenites are sourced from rhyolitic volcanism contemporaneous with the cessation of exhalative mineralisation at Liontown. As shown in section 5.1.3 the volcanism has a characteristic Mount Windsor Ti/Zr signature. The significance of the low Ti/Zr ratio, which is atypical of the Trooper Creek Formation, remains elusive however the low Ti/Zr ratio may simply be a reflection of sedimentary processes leading to breakdown of Ti-bearing minerals or sorting of Ti phases from Zr phases. Given that this effect has not been observed anywhere else in belt and the fact that the sediments are immature with well preserved glass shards, then the author's preferred, albeit speculative explanation is that these low ratios represent a more evolved period of rhyolitic volcanism possibly associated with the development of the Liontown hydrothermal system.

5.1.4 Carbonaceous Black Shale

The black shales overlie the rhyolitic cherts and arenites and show considerable thickness variation from 20 to 80m across the deposit. The shales are often carbonaceous, generally contain 1-2% disseminated pyrite and exhibit patchy silicification. Within the black shale package there are also thin intervals of arenite - siltstone and the upper most 5-10m of the unit grades into a non carbonaceous grey siltstone. The unit often exhibits an abundance of small scale (10-20cm amplitude) parasitic folds and numerous thin fracture-fill calcite veinlets.



Plate 9: Blotchy silica - sericite altered hanging wall Arenite
Drillhole LLD 128 - 285m

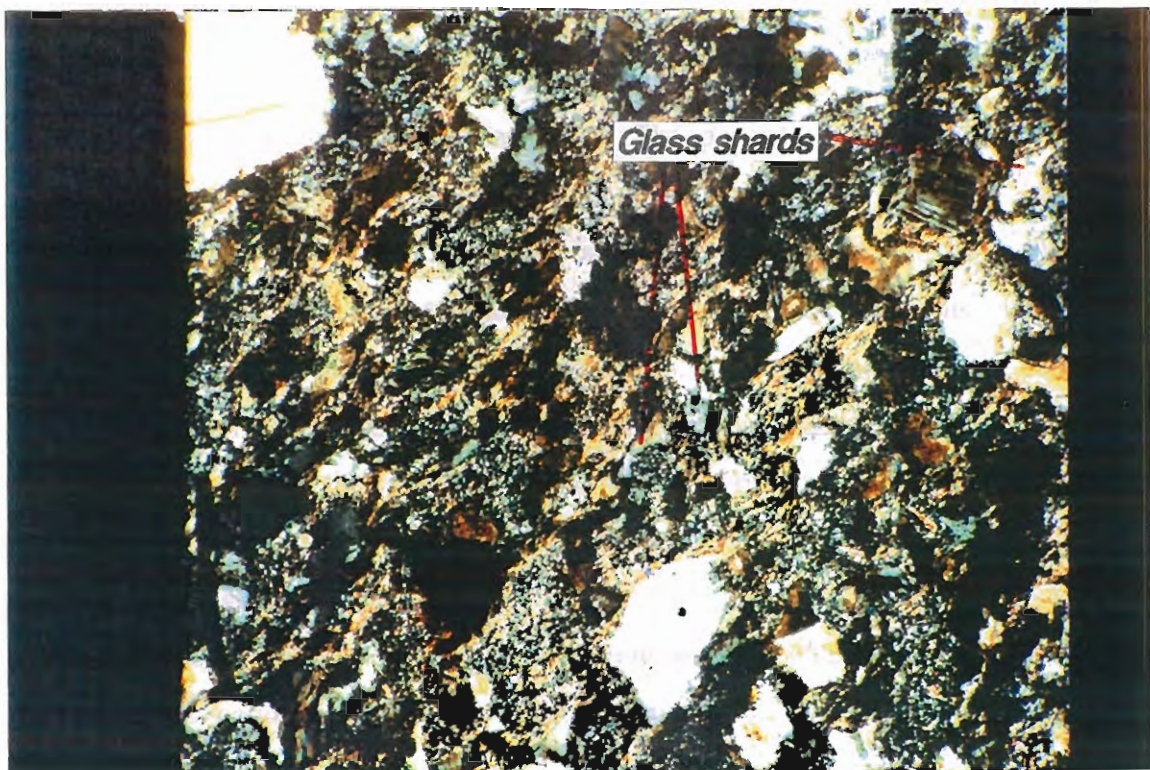


Plate 10: Photomicrograph: Hangingwall Arenite showing relict
glass shards. (Drillhole LLD128 - 285m), Scale 1cm = 500
microns.

The black shales, in contrast to the underlying cherts-arenites, are base metal anomalous with Cu to 92ppm, Pb to 77ppm and Zn to 300ppm. The average silica content is 70.40 wt % SiO₂ and the Ti/Zr ratio is broadly "dacitic" in the range 20-26 (Figure 8, Appendix, Table 4).

5.1.5 **Dacite Lavas and Associated Volcaniclastics**

The black shales are overlain by feldspar-phyric dacite lavas. The dacite is located 100-150m stratigraphically up sequence from the Liontown Horizon, has a strike length of 1.1km and varies in thickness from 50-100m. The dacite consists of a series of flows intercalated with occasional thin siltstone intervals. The coherent dacites have a weak to moderate foliation and a relatively homogeneous distribution of feldspar, augite, hornblende and minor quartz phenocrysts.

The base of the dacite rests on a 5-10 metre layer of crystal-rich dacite-derived, coarse grained volcaniclastic and minor interbedded siltstone. Within these sediments peperite textures have been recognised (Plate 11). The peperites comprise thin (1-2cm wide) lensoidal or finger like lobes of dacite lava that appear to have burrowed into unconsolidated wet sediments along the basal contact of the dacite flow. Within a few metres of the interface between the lavas and underlying sediments, small spheroidal features are present adjacent to the peperite zones. At first these appear to be accretionary lapilli though on closer inspection there is clearly a strong association with fine "veinlets" of dacite. In thin section the spheroid rims are visible as brown zones of altered fine siltstone-ash bearing a high percentage of cusped well preserved relict glass shards. The spheroids are apparently graded or at least show bands of different grain size ash (plate 14). Some of these features appear to be related to alteration whereas others such as the one shown in plate 14 are good candidates for accretionary lapilli. Although formed principally in subaerial environments, accretionary lapilli may be deposited, redeposited or reworked in subaqueous settings (Mcphie et al, 1993). If these features are indeed accretionary lapilli combined with the observation that the Liontown area has rapid facies variations, then this could indicate the Liontown deposit was located near a subaerial volcanic centre and may



Plate 11: Peperite textures - dacite and ashy siltstone. The black feldspar phyric dacite has burrowed into the brown-grey siltstone. Drillhole LLD128-186m.

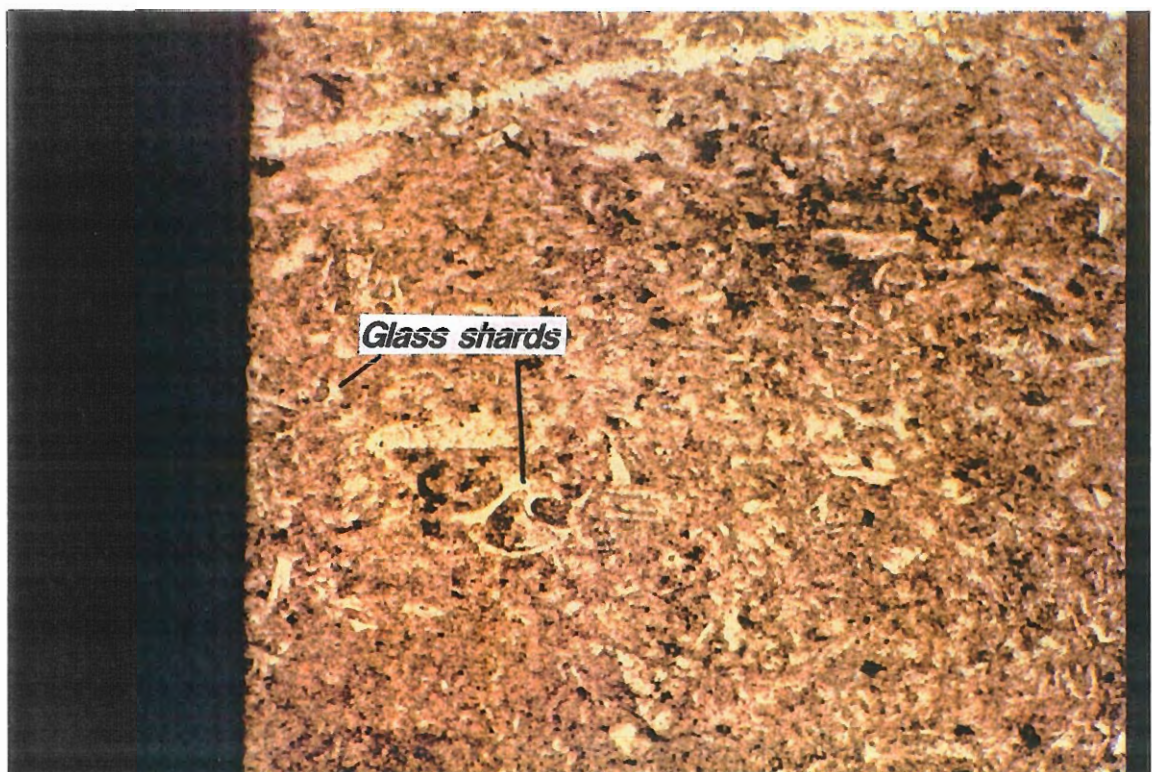


Plate 12: Photomicrograph plane transmitted light. Ashy siltstone adjacent to peperite zone and showing abundant glass shards. Scale 1cm = 500 microns. Drillhole LLD128.



Plate 13: Apparent accretionary lapilli preserved in ashy siltstone
Drillhole 128-183.3m.

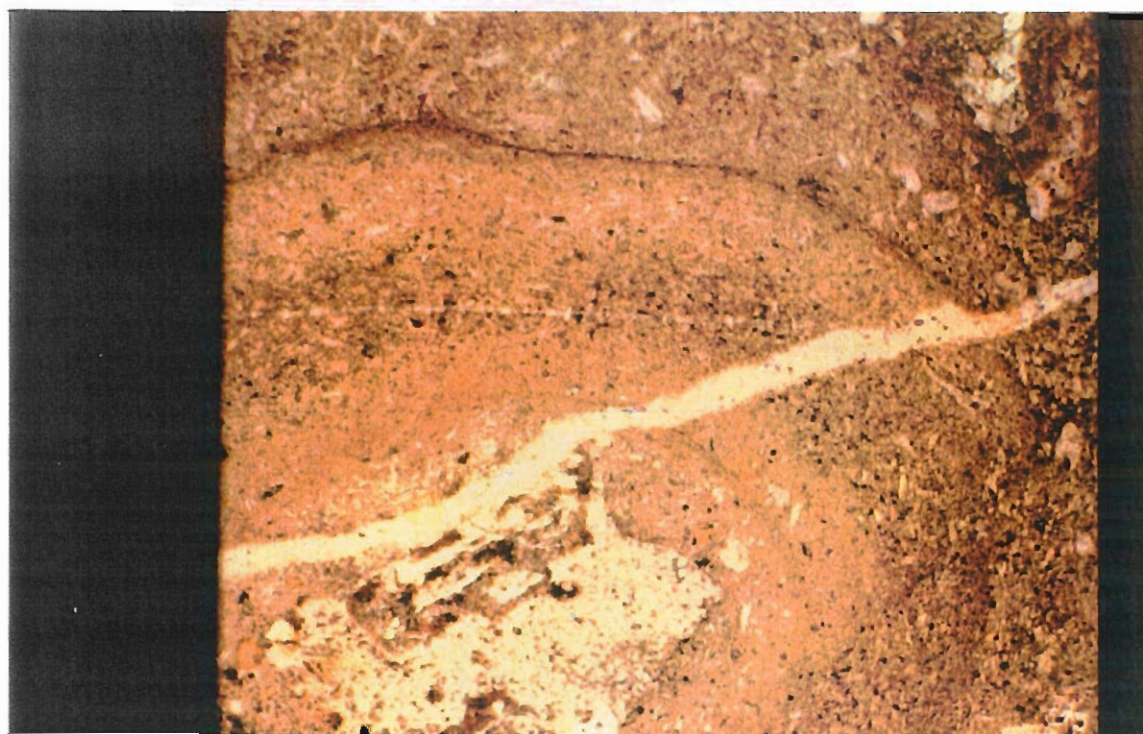
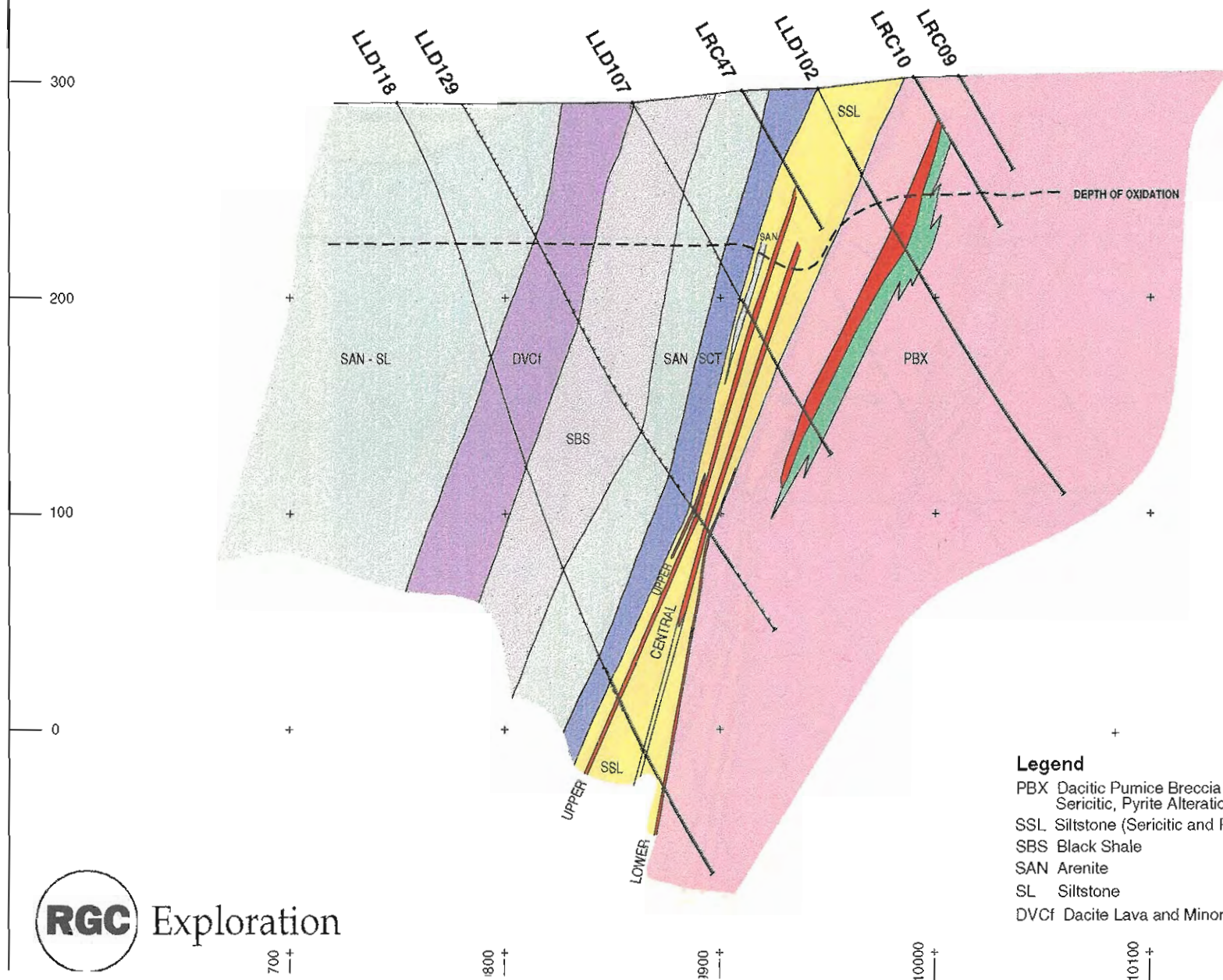


Plate 14: Photomicrograph; plane transmitted light. Portion of
an accretionary lapilli showing concentric banding
around a feldspar-quartz nucleus. Scale 10cm = 2mm.

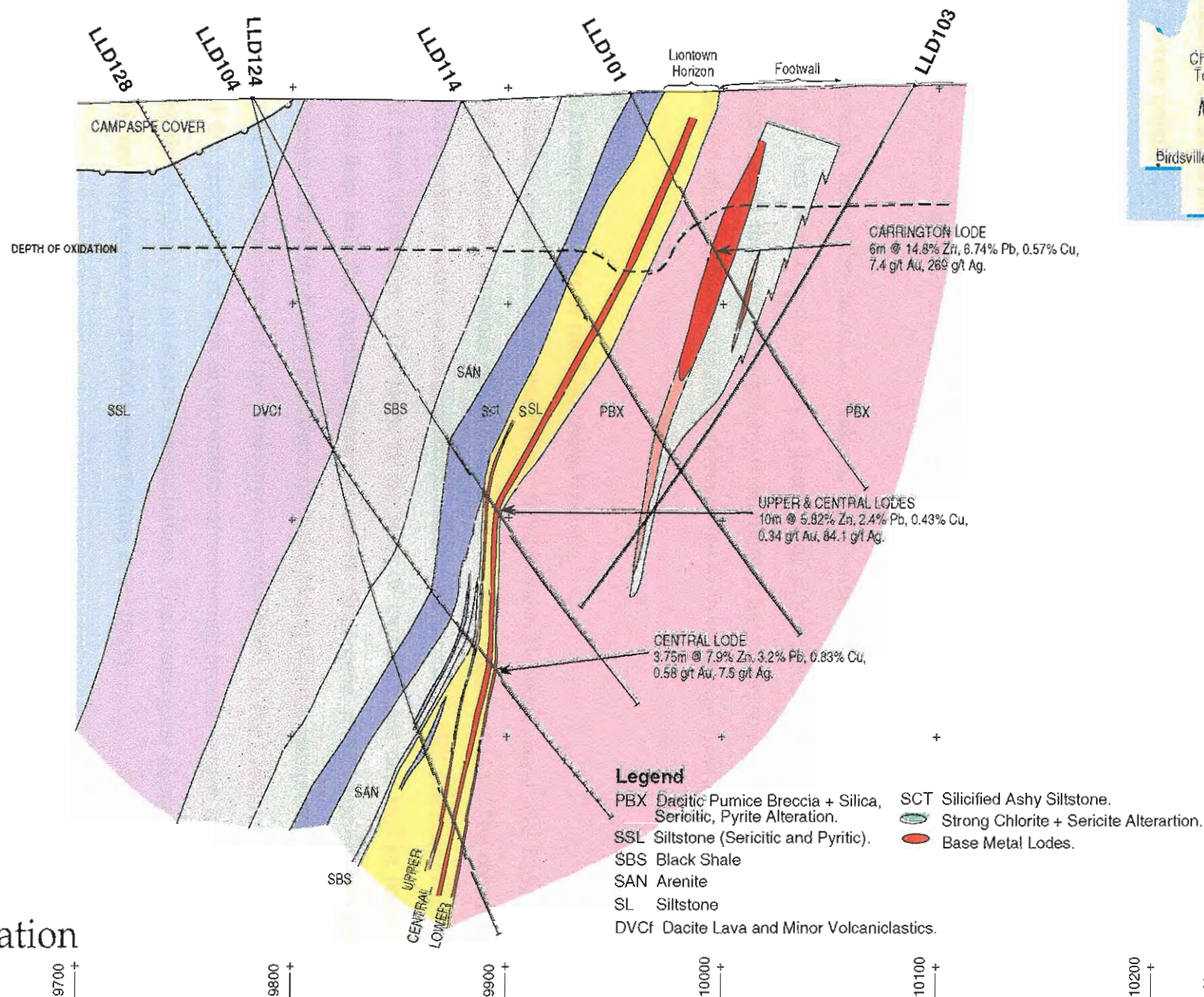
Mount Windsor Project Liontown Section 10100 E



Legend

- PBX Dacitic Pumice Breccia + Silica, Sericitic, Pyrite Alteration.
- SSL Siltstone (Sericitic and Pyritic).
- SBS Black Shale
- SAN Arenite
- SL Siltstone
- DVCf Dacite Lava and Minor Volcaniclastics.
- SCT Silicified Ashy Siltstone.
- Strong Chlorite + Sericite Alteration.
- Base Metal Lodes.

Mount Windsor Project Liontown Section 10200 E



have a more shallow water setting than previously considered. It should also be stated that the distance to the inferred subaerial volcanic centre is unknown.

Figure 8 illustrates the immobile element signature of the dacites which in Figure 8b plot as a discrete population in the central part of the graph. The Ti/Zr ratio of the dacite falls in the range 11-15, not dissimilar to the footwall pumice breccia. The total abundance of titanium however, is quite different with the dacites having at least 2,000ppm more titanium than the pumice breccias. This is also reflected in handspecimen by the presence of ~5% disseminated white leucoxene in the dacite. The dacites are base metal poor, have elevated barium to 2,620ppm and have a silica content of 62.3 wt % SiO₂ (Appendix, Table 4).

The stratigraphy above the dacite is blanketed by Tertiary sediments of the Campaspe Formation and has been tested by only a handful of drillholes in the Liontown area. Drillhole data suggest the upper stratigraphy is dominated by a monotonous succession of unaltered bedded siltstone that may mark the base of the Rollston Range Formation.

5.2 Mineralisation

5.2.1 Stratiform Exhalative Lodes of the Liontown Horizon

The mineralisation comprises three, stratiform, tabular lodes (Upper, Central and Lower) hosted within the sericitic siltstones of the Liontown Horizon (Figures 9-10). The central lode crops out as subtle gossanous-manganiferous material on Liontown Hill and is oxidised to a vertical depth of 60-80m. The lodes in the zone of oxidation are depleted in base metals to less than half the original hypogene levels. Supergene mineralisation is of restricted tonnage relative to other VHMS deposits in the Mount Windsor subprovince. The combination of high carbonate and low chalcopyrite-pyrite levels in the Liontown system has retarded the production of acid in the oxidation/weathering process which has in turn restricted the development of supergene mineralisation. Total supergene copper sulphide (chalcocite) is unlikely to exceed 30,000 tonnes (Miller et al, 1995).

The **upper lode** occurs near the stratigraphic top of the Liontown Horizon and is typically thin (1-2m) and discontinuous. The lode consists of the high levels of barite (10-33%), rare hematite blebs, cherty laminations and has an overall banded-bedded appearance. The lode also has elevated total silica between 15-39wt % SiO₂ which is considerably higher than the silica levels in the carbonate dominated central lode which has SiO₂ levels of between 4.71-

6.47wt % (Appendix, Table 4). Base metal levels are relatively low, seldom exceeding 2% zinc and gold is often elevated to 0.8-1g/t. The upper lode is interpreted to have been deposited from the exhalation of hydrothermal fluids onto the seafloor.

The Liontown stratiform lodes are characterised by the presence of low iron sphalerite. Within the lodes there is a visual zonation from grey-brown sphalerite in the lower lode to cream coloured sphalerite in the central and cream-white sphalerite in the upper lode. In summary there is a zonation from moderate-high iron sphalerite at the base of the horizon to low iron sphalerite at the top. This zonation may reflect varying redox conditions at the site of deposition (Hannington and Scott, 1989), relatively reduced during the deposition of the lower lode through to more oxidised conditions for the upper lode.

The **central lode** is situated 5-10m stratigraphically below the upper lode within the central portion of the Liontown Horizon. This lode is the thickest of the stratiform bodies, typically having a true thickness of between 3 to 12 metres. The central lode has a strong calcite-sphalerite-barite association and banding is rare to absent. The carbonates within and adjacent to the lode typically exhibit blebby to coarsely crystalline massive recrystallisation textures. The ore mineralogy is dominated by semi-massive, low iron sphalerite, minor galena and chalcopyrite and trace amounts of tennantite-tetrahedrite.

In thin section the sphalerite forms <300µm thick streaky layers of <200µm anhedral. The sphalerite, sericite and chlorite preferred orientation defines a very strong schistosity. The observation of microshear bands and asymmetric tails developed around quartz and calcite crystals suggest the base metal sulphides have undergone some degree of transposition.

The central lode carries the best metal grades of all the stratiform lodes in the Liontown Horizon. A particularly good intercept assays in the order of 5-7% Zn, 2-3% Pb, 0.2-0.45% Cu, 0.3-0.8g/t Au and up to 80g/t Ag. Barium values are erratic and in the range 0.2% and 14% Ba. The central lode also has elevated manganese up to 2% which varies in accordance with the total CaO content.

There is no unequivocal evidence to show whether the central lode was formed by the exhalation of base metal sulphide onto the seafloor, or alternatively by near seafloor replacement processes. The primary textures of the central lode have been modified by

deformation and recrystallisation. Nevertheless, there are features in favour of near seafloor replacement. These include the occurrence of barite as predominantly stringers and blebs, the absence of a barite-silica cap (which is clearly evident overlying the upper lode), the observation that the central lode appears to transgress the Liontown Horizon and gives way to semi-massive carbonate along its fringes, and the absence of banded/bedded textures that are characteristic of the upper lode. Deformation can easily destroy many of the primary features expected of exhalative mineralisation however at Liontown these features are preserved in the upper lode (which has experienced the same degree of deformation as the central lode), therefore if the central lode was exhalative, primary exhalative textural features if originally present should be preserved as is the case with the upper lode.

The **lower lode** is particularly noncontinuous and rests on the Liontown Horizon-pumice breccia contact (figure 10). This lode seldom exceeds a true thickness of half a metre and has a strike length of no more than 200 metres. The lower lode consists of minor semi-massive sphalerite and galena, though is usually dominated by a network of sphalerite-galena, quartz+carbonate and barite stringers.

5.2.2 Carrington Lode

The Carrington lode is a "cigar-like" body of massive to semi-massive sphalerite-galena-pyrite mineralisation developed 30-50m stratigraphically below the Liontown Horizon - pumiceous breccia interface (figure 10). The degree of alteration enveloping the ore zone is intense and has totally detextured the host lithology. The host is a sericite-chlorite, pyritic schist. Figure 4 depicts the immediate stratigraphy above and below the Carrington lode and illustrates that the footwall sequence clearly comprises not one, but a series of volcanoclastic mass flow units. Above the Carrington lode and below the Liontown Horizon, the stratigraphy is dominated by two relatively coarse pumice breccia units separated by a thin (0.25-0.5m) siltstone interval. Below the lode the sequence consists of numerous silica-sericite altered pumice breccia units. Within the basal sequence there are often feldspar phyric, chloritic schists preserved, usually in close proximity to the margin of the sericite halo enveloping the Carrington lode.

The ore textures of the Carrington lode have been modified by deformation and recrystallisation. The high grade ore has an intense foliation and is often sheared giving some zones an apparent banded/bedded appearance. Within the high grade core the

sphalerite is a honey brown to grey colour and below, particularly in the chlorite schists, the sphalerite is the cream coloured low iron variety. Replacement textures are common immediately below the high grade ore zone and vary from sphalerite clots replacing pyrite to spots of low iron sphalerite with sericitic rims and rare euhedral feldspars partially replaced by sphalerite (Plates 15 - 18). The spotty ore texture is visually similar to the spotted textures reported by Khin Zaw and Large (1992) from the South Hercules deposit. Khin Zaw and Large argue that because the degree of metamorphism and deformation in the South Hercules area is more or less similar to that at Rosebery, and the spotty ores are lacking at Rosebery, then it seems unlikely that metamorphism and deformation produced the ore textures. They consider the spotty ore textures to reflect an original open-space filling and/or replacement process in porous volcanoclastics. At Liontown the stratiform base metal sulphides lack the spotted textures and yet they are located only 30 to 50 metres away from the Carrington Lode. Thus the same reasoning used by Khin Zaw and Large (1992) is invoked for the origin of the Carrington lode spotty ore textures.

The Carrington lode is the high grade portion of the Liontown system and typically reports grades in the range 6-8m @ 9-15% Zn, 3-6% Pb, 0.2-0.6% Cu, 1-6g/t Au, 40-100g/t Ag. The bulked lode resource is estimated at 370,000 tonnes @ 0.30% Cu, 2.6% Pb, 7.6% Zn, 20g/t Ag and 1g/t Au. Unlike the exhalative mineralisation of the Liontown Horizon, in the Carrington lode barite has not been observed. Sodium depletion is particularly strong within the sericite alteration envelope with levels typically in the 0.02 to 0.10wt % range. Carbonate is a relatively minor component.

Throughout the ore zone the Ti/Zr ratio averages around 15, however there are significant departures from the average to as low as 3.09. Figure 11 shows a strong correlation between high grade zinc (>7%) and low Ti/Zr ratios. These results are due to lower titanium and higher zirconium levels in the massive sulphide zone. The absolute levels of titanium 1000-3000ppm and zirconium 200-416ppm remain relatively high, and Ba is at background levels, this data reduces the possibility of an exhalative origin for the massive sulphide. Given the very low Ti/Zr ratios do not represent a primary rhyolitic signature at the high grade ore position and the good correlation between Ti/Zr and Zn, it would seem reasonable to interpret the results as strong evidence for significant Ti and Zr mobility in the immediate ore forming environment of the Carrington lode. It is possible that the drop in Ti/Zr at higher zinc levels is an analytical affect, this however is considered unlikely

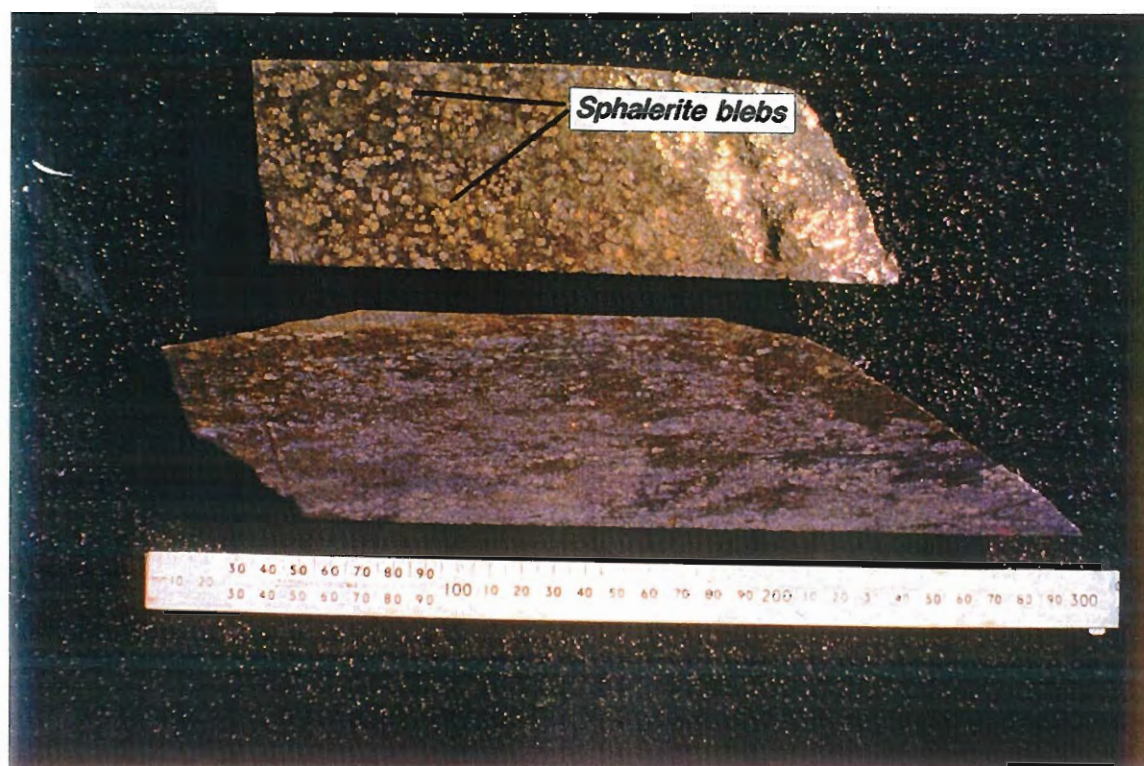


Plate 15: Carrington lode - Blebby sphalerite replacement textures and strongly foliated semi-massive sphalerite and galena
Drillhole LLD132 - 72m

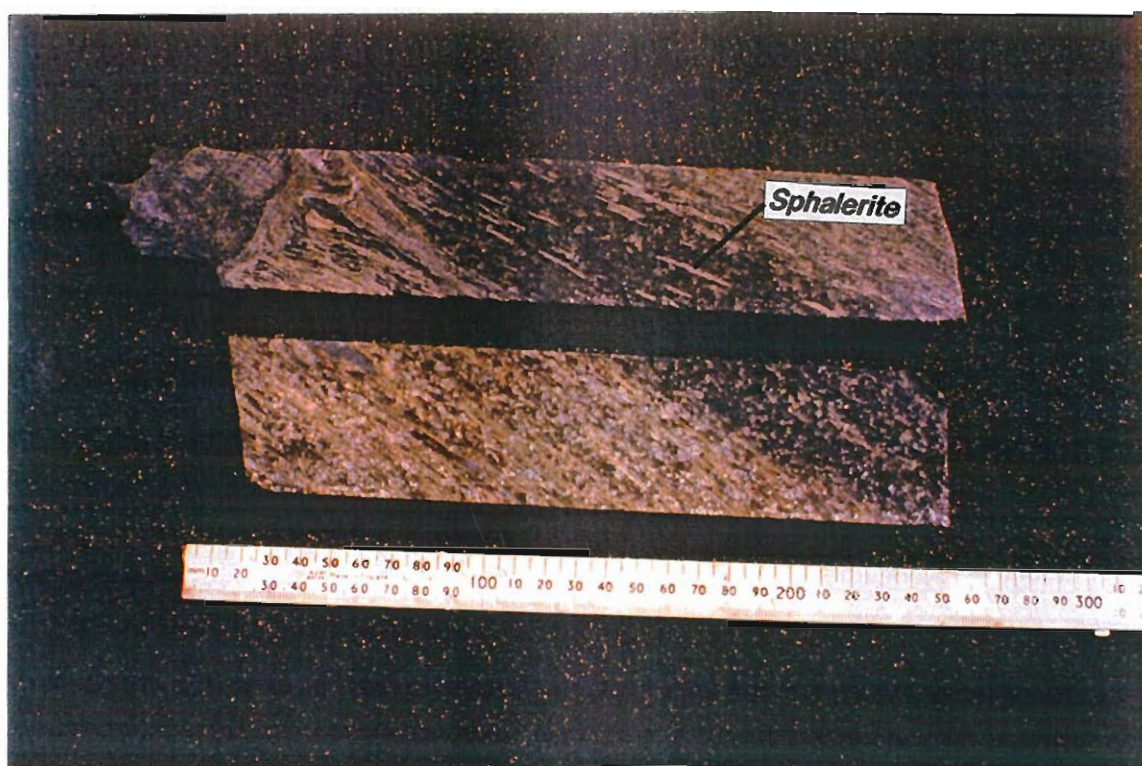


Plate 16: Carrington Lode - Elongate low iron sphalerite blebs transposed along foliation of feldspar-chlorite schist.
Drillhole LLD132-88m

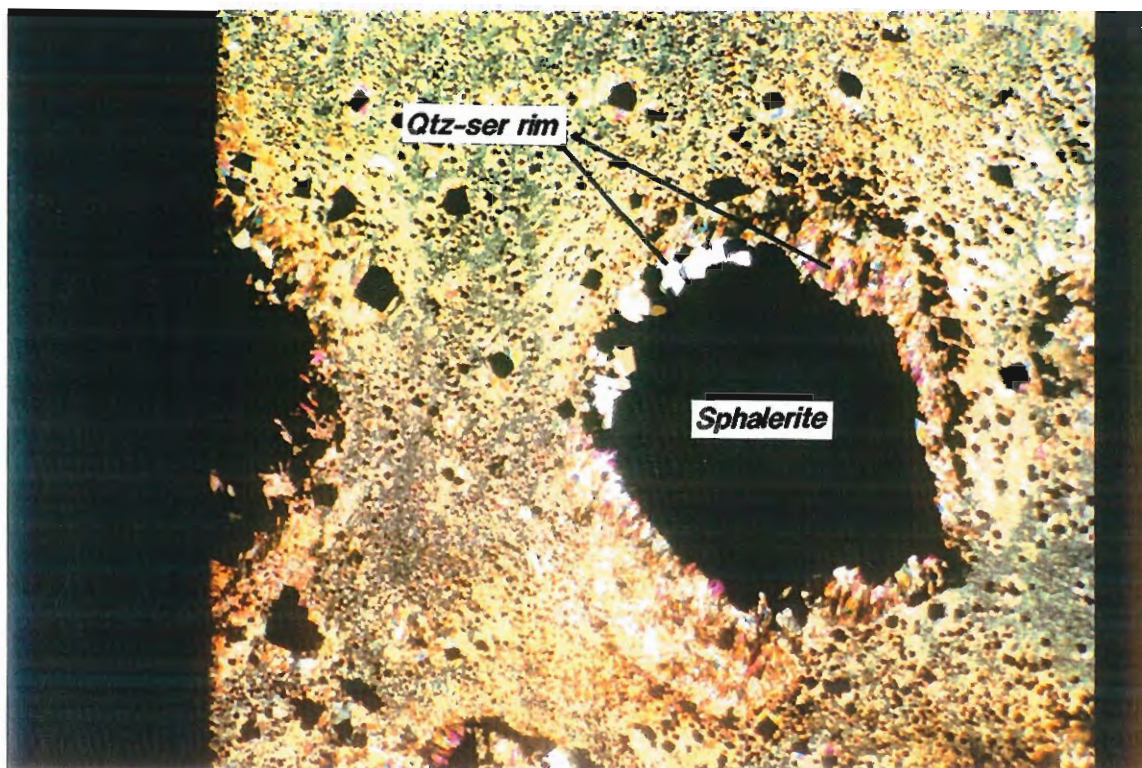


Plate 17: Photomicrograph: crossed polarised transmitted light
 Sphalerite replacement bleb with sericite-quartz rim set in
 sericite-chlorite schist - Carrington Lode. Drillhole LLD132
 Depth 77.7m. Scale 1cm = 0.5mm.

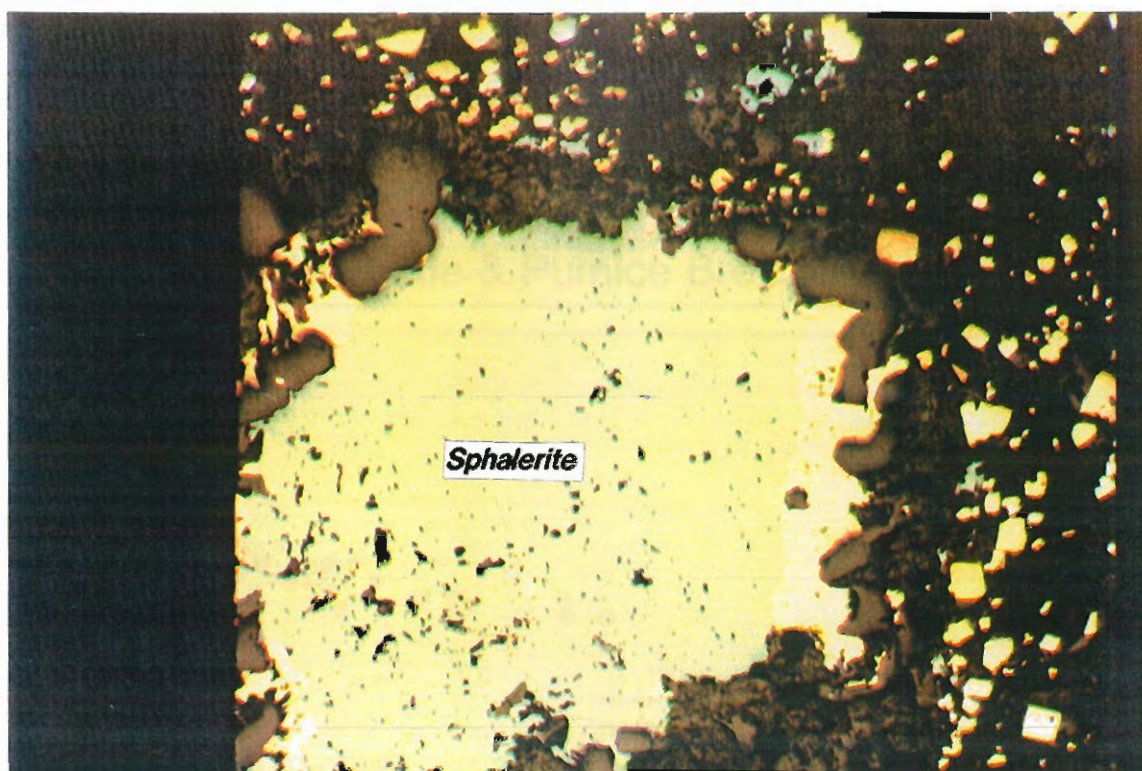
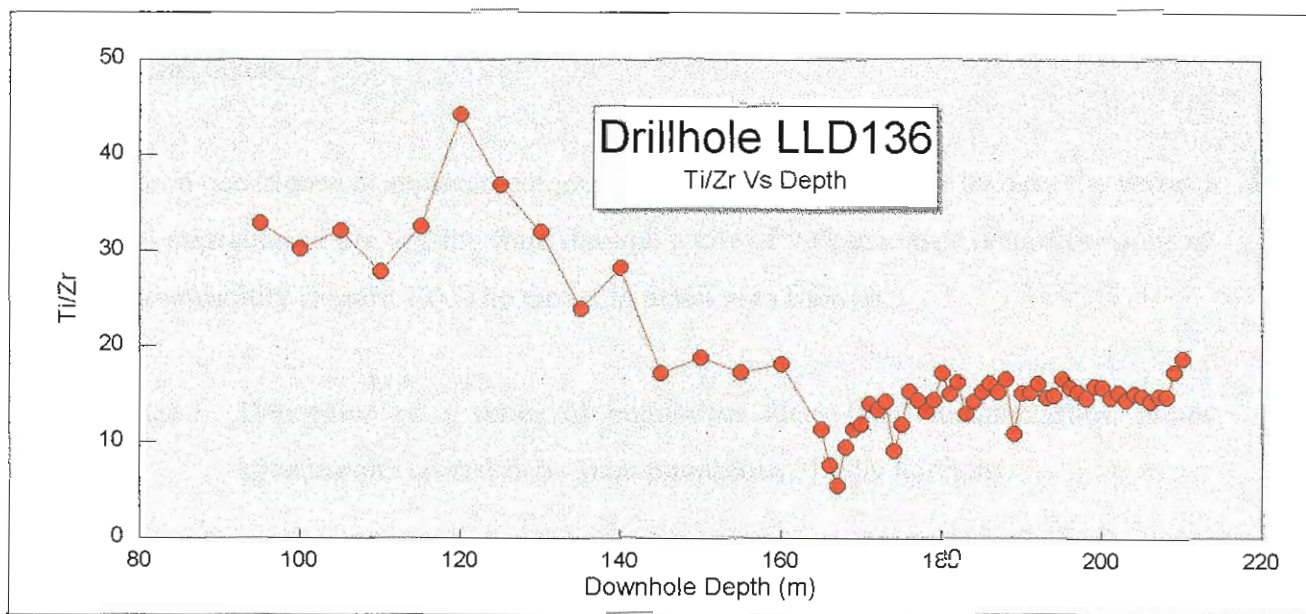
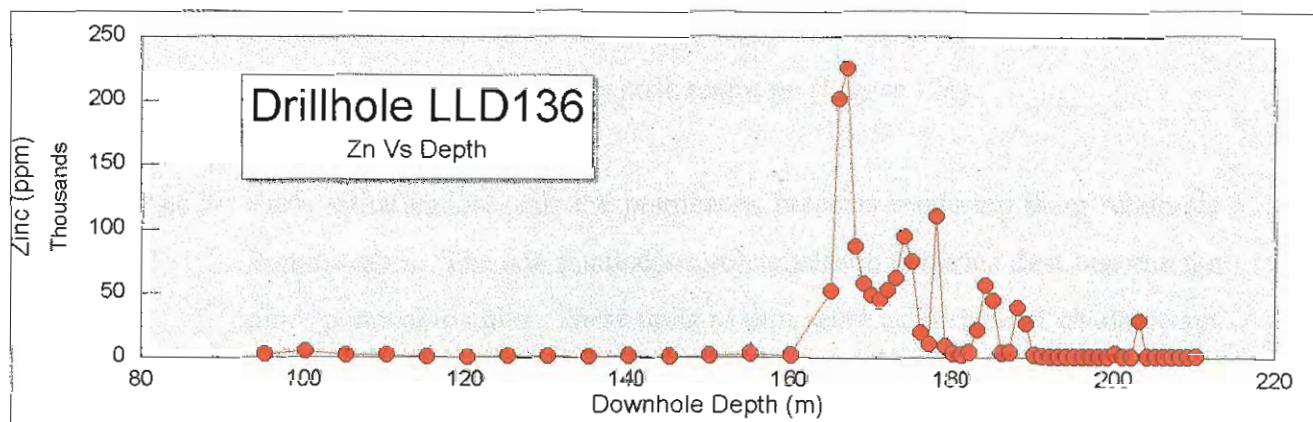


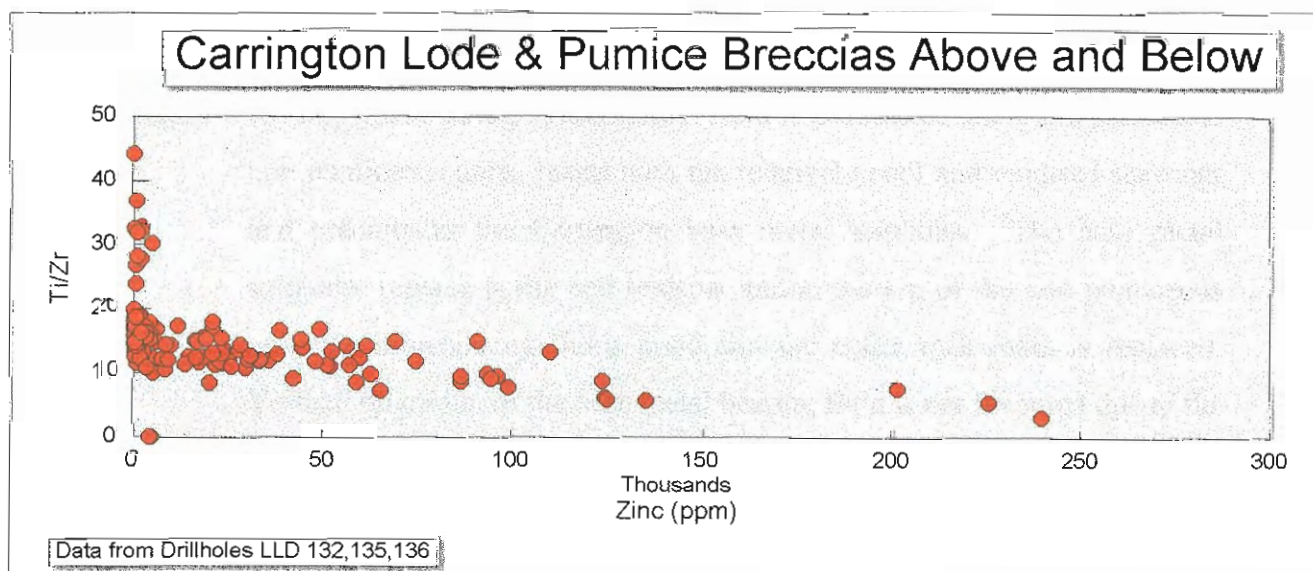
Plate 18: Photomicrograph reflected light, Sphalerite replacement
 bleb with chalcopyrite spotting and rimming. Drillhole
 LLD132-77.7m Scale 1cm = 0.25mm



[a]



[b]



[c]

Figure 11: Carrington Lode and foowall pumice breccia Ti/Zr and Zn plots.

a significant Cu-Au stringer zone is present between sections 9900E and 10050E at depths in the range 25-100m below surface. The stringer zone occurs immediately below the main zone of zinc accumulation in the stratiform lodes. Interestingly the stringer zone is not situated below the Carrington lode, instead it is located adjacent to its western margin.

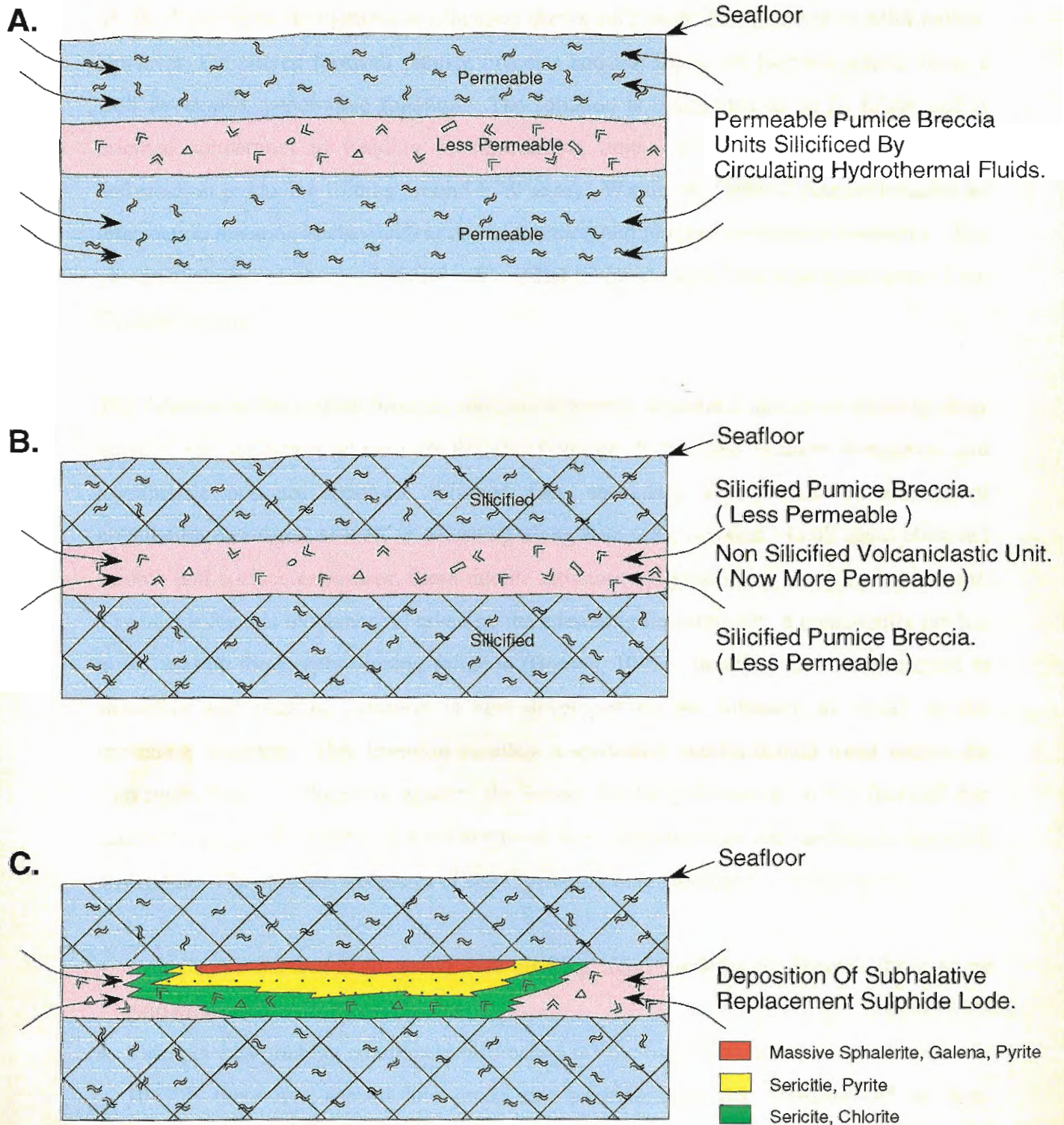
5.3 Structure

Much of the upper stratigraphy at Liontown shows only weak, non-penetrative deformation. However, the altered footwall pumice breccias and the Liontown Horizon schists show a well developed, penetrative foliation. The foliation is interpreted as an S_2 fabric and is oriented subparallel to bedding in surrounding units (S_2 is related to D_2 regional deformation producing folding around E-W axes). Within the footwall pumice breccias an intersection lineation is also evident on the foliation and plunges moderately eastwards. The plunge of the lineation is essentially sub-parallel to the plunge of the high grade core of the Carrington lode.

The foliation in the pumice breccias contains numerous kinematic indicators showing shear sense. The indicators present in the foliation are ductile and include symmetric and asymmetric pressure shadows, foliation fish, secondary shear bands or extensional crenulation cleavages, as well as offsetting along core scale markers. In all cases observed in core and surface exposures, these ductile structures suggest south block up movement. The vector for this movement is given by the stretching lineation which consistently pitches at 65° east on the steeply dipping foliation (Beeson, 1995). In addition a sub-horizontal to shallowly east pitching lineation is also developed on the foliation, at $50-60^\circ$ to the stretching lineation. This lineation parallels a secondary sub-horizontal trend within the Carrington lode. It therefore appears the strong ductile deformation in the footwall has caused lensing and podding of the Carrington lode parallel to the two dominant lineation directions. The resultant geometry of the Carrington lode includes two components;

- a single sub-horizontal to gently east pitching trend immediately beneath the base of oxidation, and
- a steeply east pitching component bifurcating off the base of the sub-horizontal zone. At 10490E there is a second low grade east pitching zone that branches off the sub-horizontal zone (Figure 13).

CARRINGTON LODGE - PROPOSED MODEL OF FORMATION



An interesting feature of the Carrington lode is the observation of localised foliation dip reversal in the high grade core of the lode. The foliation routinely dips at $\sim 70^\circ$ south, however the thickened and high grade core can have dips of between 90° and 70° north. These zones are interpreted as areas of localised thickening generated by either south block up movement producing stacking and therefore local thickening or discrete elongate S shaped flexures.

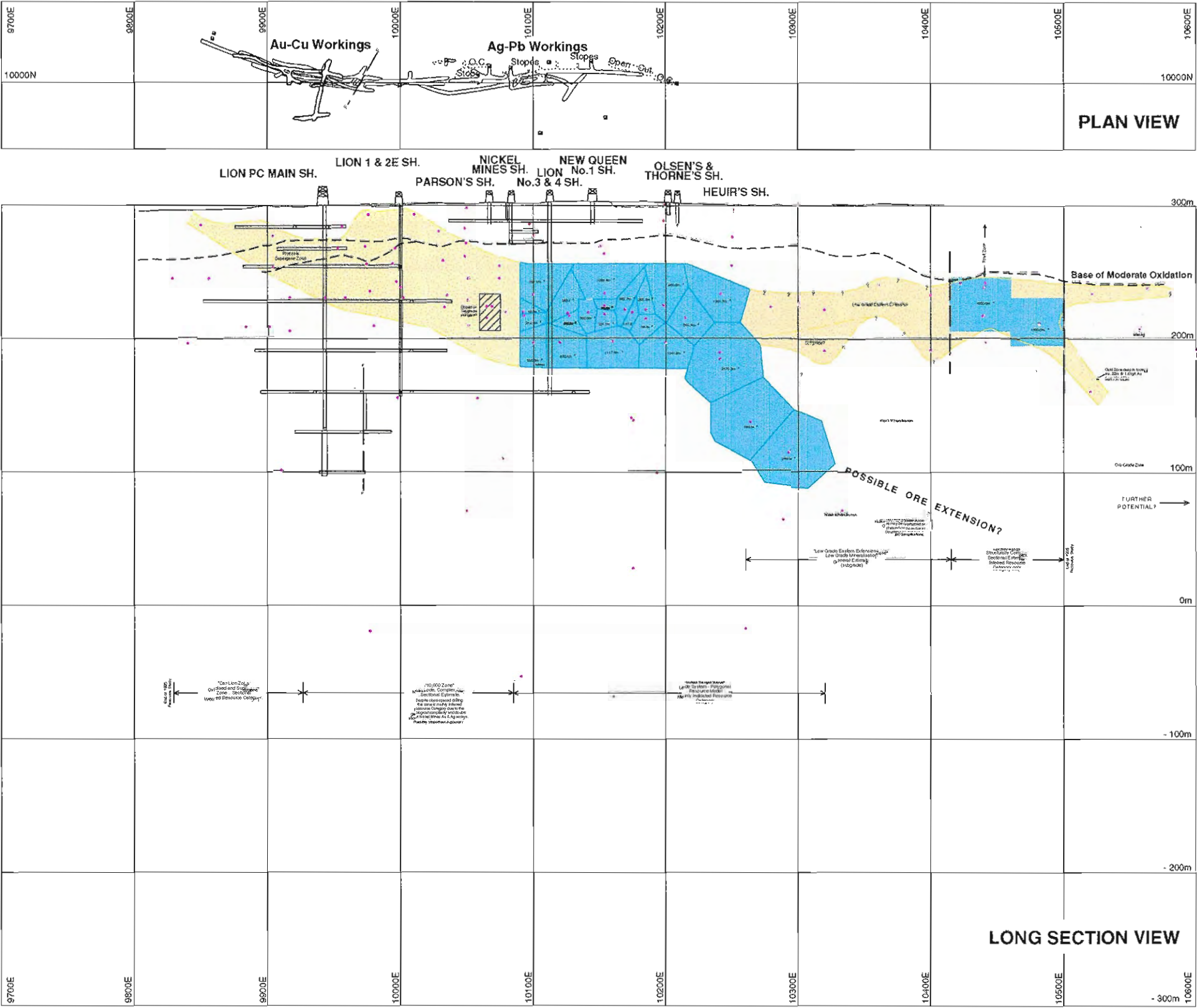
Syn-volcanic growth faults are considered a controlling feature in the location of VHMS deposits and are inferred to serve as the major focus for the movement of metalliferous hydrothermal fluids up through the volcanic pile and onto the seafloor (Large, 1991). In the Liontown area there have been two growth faults identified (Berry et al, 1991 and Maclean, 1985). The Oaky Creek growth fault is a major discontinuity delineated over a distance of 5kms displacing the Puddler Creek, Mount Windsor and Trooper Creek formations (Plate 1). The fault appears to terminate at the Liontown Horizon. The centre of the Liontown deposit is located 600m to the east of the fault and the Tigertown-Cougartown centre is situated 900m west of the fault. The Oaky Creek growth fault is therefore inferred to be the key focus of the Tigertown-Liontown plumbing system.

The other identified growth fault at Liontown is situated on section 10400E and has been inferred from a dramatic thickening of the hanging wall sediments encountered in the deep diamond hole LLD127 (720m). Further support for this interpretation includes the presence of abundant coarse polymictic sedimentary breccias in the thickened stratigraphy. Although there is no supporting evidence, other than the proximity to Liontown, the 10400E growth fault may also have some influence on the immediate plumbing system below the Liontown deposit. If this is the case, then the relatively unexplored area to the east of 10400E may have further potential (Figure 13).

6.0 SATELLITE HYDROTHERMAL SYSTEMS - LEOPARDTOWN, TIGERTOWN AND PANTHERTOWN

The **Leopardtown** stringer pyrite zone and its enclosing alteration is situated 2.6km to the northeast of Liontown and occurs approximately 700m lower in the stratigraphy. The Leopardtown prospect consists of an 800m long pyrite gossan developed in hydrothermally

CARRINGTON LODGE RESOURCE LONG SECTION & HISTORIC WORKINGS



altered siltstone and dacitic volcanoclastics. An historic diamond hole drilled by Nickel Mines Ltd in the 1970's intersected 11 metres of massive pyrite below the central part of the gossan. Although the gossan is long and sinuous with open folding evident, consistent with northeast southwest directed compression producing wavelengths of 200m, the enclosing alteration system is stratabound and strike parallel with the stratigraphy to the north and south.

Leopards town has for many years been of particular interest to VHMS explorers and has been referred to as the Leopards town "favourable" horizon. Drilling at Leopards town by Pancon intersected an alteration assemblage comprising sericite-pyrophyllite-silica-pyrite-fluorite-kaolinite, topaz (pyrophyllite identified from XRD analyses). Stolz (1991) considers the quartz-topaz-pyrophyllite alteration assemblage at the Trunccheon prospect to be post Devonian because the phyllosilicates have no preferred orientation (not aligned by the Devonian deformation). At Leopards town the sheet silicates define a strong foliation and therefore are likely to predate the Devonian deformation.

There is no clearly defined exhalative position at Leopards town, that is there has been no stratiform barite-jaspers or base metal sulphides recognised (though the historic intercept of massive pyrite may be a candidate for exhalative material). The system is base metal poor with zinc and lead seldom exceeding 1000 ppm and more generally within the range 50 to 100 ppm. Pyrite stringers within the central portion of the alteration envelope do however carry elevated copper to 0.48% and gold to 0.3g/t.

A technique for distinguishing between VHMS and non VHMS mineralisation is the zinc ratio $[100 \text{ Zn}/(\text{Zn}+\text{Pb})]$ as defined by Huston and Large (1987). Volcanogenic massive sulphide deposits in the Mount Read Volcanics of Tasmania have zinc ratios which fall in a restricted range of mean values (60-77) with low standard deviations of less than 15. At Leopards town all non-oxidised samples from diamond core hole LPD001 (Plate 1a) were used to calculate a mean zinc ratio of 66 with a standard deviation of 17. This represents the zinc ratio for the altered core of the system. When anomalous samples with lead and zinc values exceeding 100 (ppm) were used a mean zinc ratio of 70 with a standard deviation of 9 was obtained. The Leopards town zinc ratio is therefore in accordance with the ratio expected for VHMS mineralisation of both the Mount Read and Mount Windsor Volcanics.

Sulphur and lead isotopes were also used in an effort to characterise the Leopardtown hydrothermal system. The results are equivocal and have been presented sections 8.4 and 8.5.

The **Tigertown** barite-sphalerite-pyrite prospect is located 1.5kms to the west of Liontown and has been shown through mapping and drilling to be an approximate time equivalent of the Liontown stratiform position. The Tigertown mineralisation is situated adjacent to a small growth fault marking the boundary between a thick succession of siltstones to the east and a relatively thin sequence of siltstone, arenite and dacitic volcanoclastics to the west (Plate 1).

In ascending order, from the footwall stringer zone (Cougartown) through to Tigertown, the stratigraphy consists of dacitic feldspar-phyric pumice breccia, andesite and a thick sequence of silica-sericite-pyrite altered siltstone which includes six poorly developed exhalative barite-carbonate horizons (Figure 14).

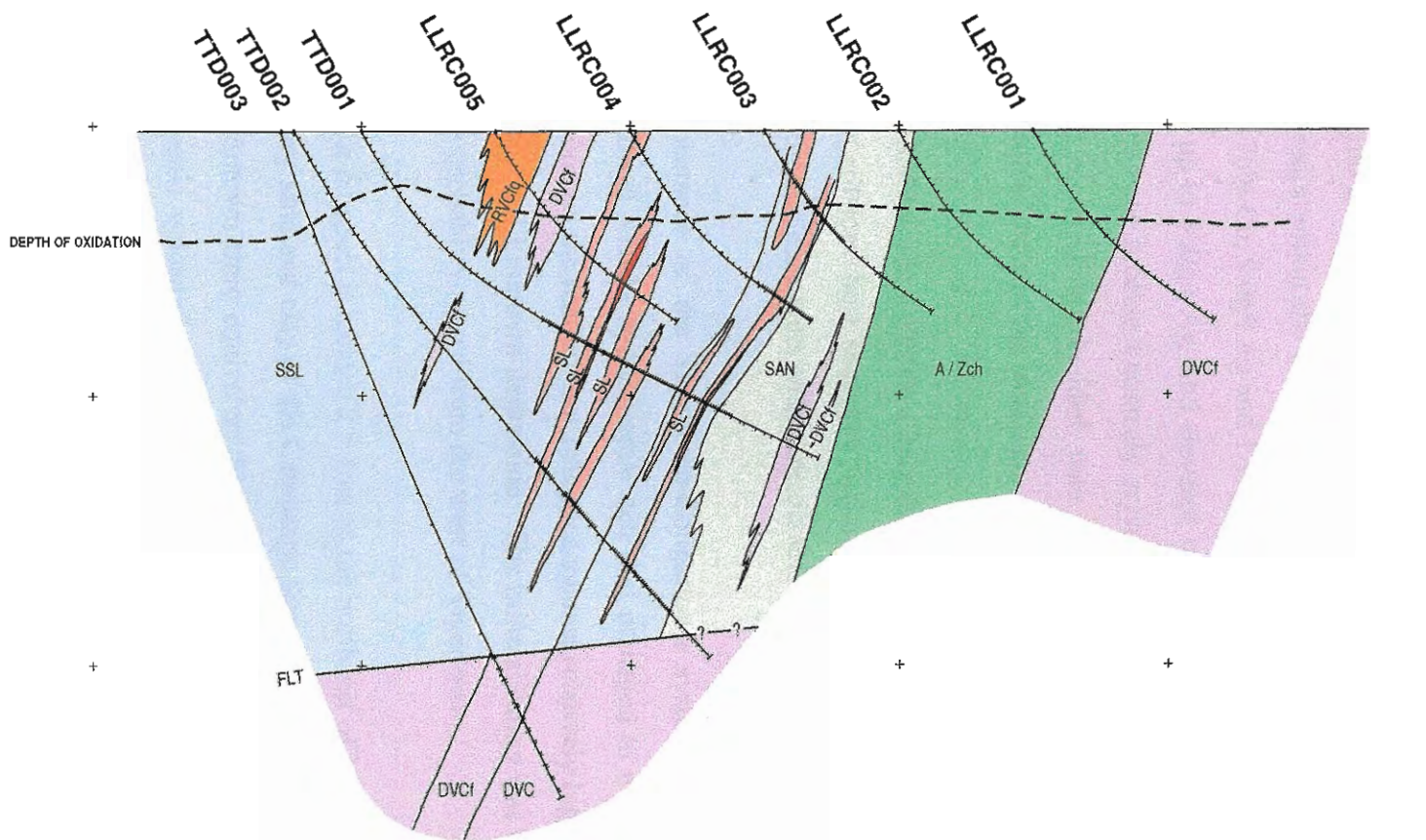
The **Cougartown** gossan is located 200 metres to the north of the stratiform mineralisation at Tigertown. The gossan is Pb and Zn enriched and developed in variably altered dacitic volcanoclastics. A series of percussion and diamond drillholes intersected a weak pyrite-sphalerite stringer system beneath the gossan which is hosted by pumice breccia correlated with that at Liontown (Maclean, 1985). At Cougartown the intensity of alteration varies from zones of intense silica flooding (identical to the silica augen-chloritic lenticle texture in the Liontown footwall) through to zones of relatively weak-moderate alteration comprising blotchy silica and pink albite. It is these domains of silica-albite alteration that have preserved the primary textural features - clusters of broken feldspars, lithic fragments and pumice.

An interesting aspect of the Cougartown system is that the sphalerite is only present in areas of intense silica-albite alteration and feldspar preservation. Furthermore, the Cougartown (footwall) sphalerite is the brown-red high iron variety, whereas the Tigertown (stratiform exhalative) sphalerite is the cream-white low iron variety. The process responsible for the "sphalerite zoning" is likely to be a function of redox conditions and to a lesser extent temperature and/or trace element content. At Liontown there is a similar sphalerite zonation

Mount Windsor Project Tigertown Section 8500 E



0 40km



Legend

- | | |
|---------------------------------|-------------------------------------|
| TC Tertiary Sediments | RVC Rhyolitic Volcaniclastic |
| Da Dacite Lava | SSL Siltstone |
| DVC Dacitic Volcaniclastic | SBS Black Shale |
| PBX Dacitic Pumice Breccia | SAN Arenite |
| R Rhyolite Lava | A / Zch Andesite - Chloritic Schist |
| Barite - Carbonate ± Sphalerite | Base Metal Lodes |

RGC Exploration

9700 +

9800 +

9900 +

10000 +

10100 +

10200 +

2503V005.dgn 04.06.1996 FIGURE 14

showing a well developed redox response, though the Carrington lode has both low and high iron sphalerite. Interestingly the sphalerite in the footwall (Carrington Lode) is also associated with areas of partial feldspar preservation.

Tigertown, situated to the south and stratigraphically above Cougartown, is interpreted as an exhalative, or near seafloor, part of the hydrothermal system. The Tigertown stratigraphy is dominated by silica-sericite-pyrite altered, strongly foliated siltstones and arenite with six interbedded barite-carbonate \pm semi massive sulphide horizons. The semi massive sulphide lenses are small, no greater than 1m x 20m x 20m and merge with barite and carbonate on their fringes. Grades within the core of the sulphide lenses are high and average 11.05% Zn, 5.71% Pb, 0.76% Cu, 9.0g/t Ag and 1.17g/t Au, and the barite-carbonate zones typically carry 1.3g/t Au, up to 300g/t Ag, and elevated mercury to 30ppm. The barite throughout the Tigertown sequence is often a coarsely crystalline bladed variety, though also occurs as finely laminated material interbedded with siltstone, carbonate and low iron (white) sphalerite in the upper parts of the sequence.

In contrast to Liontown, the Tigertown barites are often associated with bright red blebs of hematite and the siltstone host sequence includes a far greater proportion of arenite and coarse grained volcanoclastic units with considerable lateral facies variation throughout.

The overall appearance of the Tigertown-Cougartown system is that of a small, low temperature, oxidised VHMS hydrothermal cell that managed to exhale minor barite-base metal mineralisation on the seafloor but struggled against relatively high sedimentation rates on the edge of the local Liontown depression. The mineralisation was essentially swamped by sedimentation probably sourced from the west of Tigertown.

The **Panthertown** prospect is located 2.5 kms to the northeast of Liontown and is blanketed by 50m of Tertiary sand and clay of the Campaspe formation. The prospect is interpreted to occur on the Liontown time equivalent horizon though is dominated by coarser grained dacitic and andesitic volcanoclastics overlying a pumice breccia footwall sequence. The Panthertown system does not have exhalative material developed. Quartz-pyrite-carbonate \pm barite veining is common through the entire altered footwall pumice breccia sequence and extends at least 100 metres into the overlying dacitic and andesitic volcanoclastics. The quartz-pyrite stringers often include blebs and fine veinlets of chalcopyrite (trace - 0.5%)

and minor low iron sphalerite. The interval 237-267m in drillhole LLD138 is an impressive quartz-pyrite-carbonate stringer zone, including semi massive pyrite stringers occasionally associated with up to 2-3% blebby chalcopyrite. Surprisingly, the alteration is of only moderate intensity with feldspars preserved throughout the sequence. Blotchy pink silica-albite is common. The Panthertown prospect is interpreted as a relatively weak, low temperature and oxidised hydrothermal stringer system with a VHMS affinity.

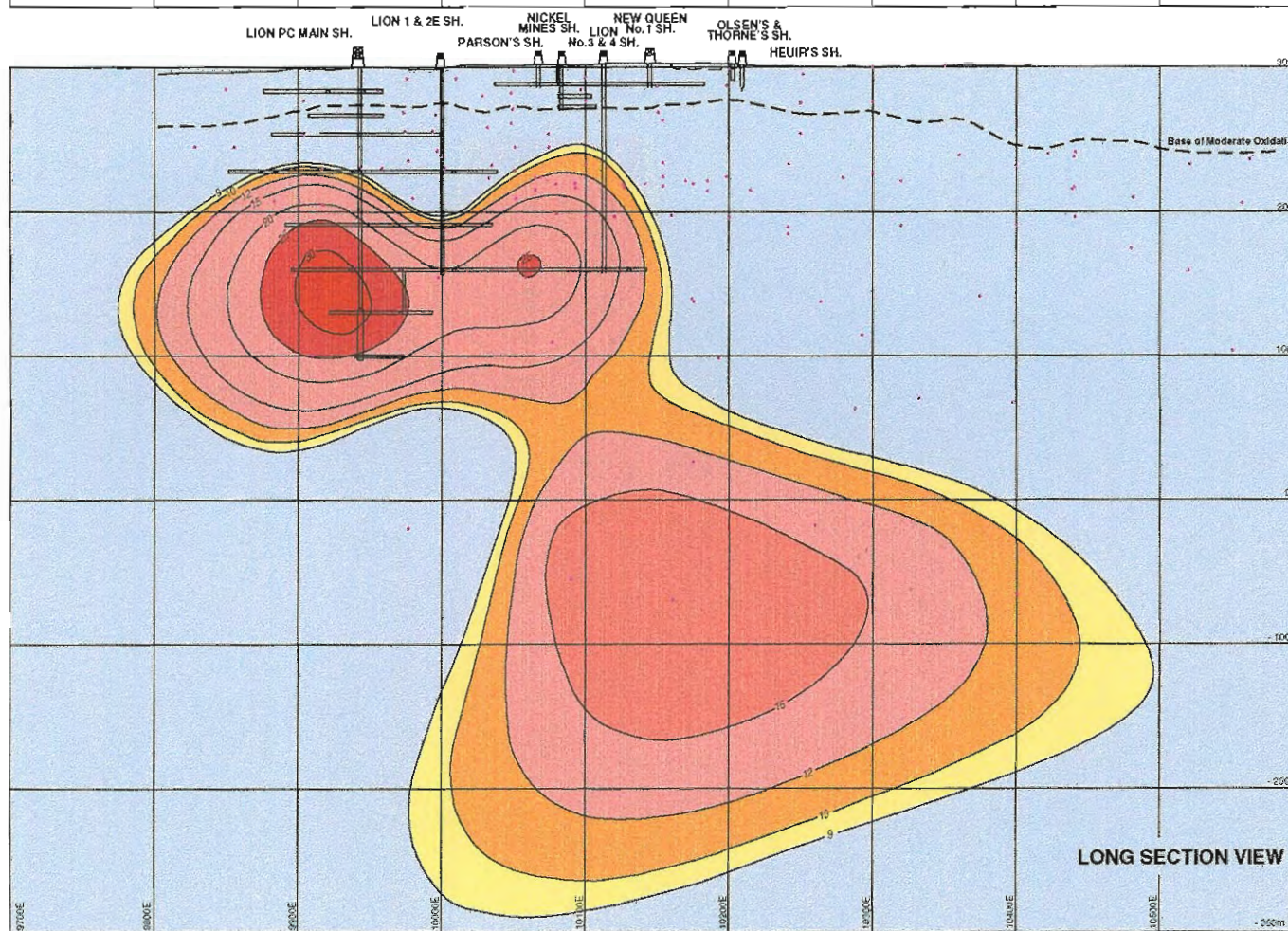
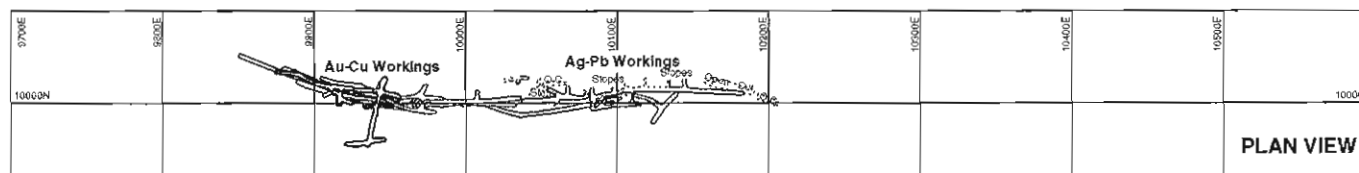
7.0 METAL ZONATION AND DEPOSITIONAL SETTING

In this study the distribution of Cu, Pb, Zn, Ag and Au were contoured on long section for both the Carrington lode and the mineralised portion of the Liontown Horizon (top of upper lode to the base of lower lode). For each data point on the long sections a metre x metal(%) or metre x metal(ppm) value was calculated to represent total metal accumulation at that point in either the Carrington lode or the Liontown Horizon. The Carrington lode data was contoured and imaged using Interdex software and the Liontown Horizon contoured using the Geosoft gridding and contouring package. Downhole profiles were also constructed to illustrate the vertical distribution of Cu, Pb, Zn, Ag, Au and Ba.

7.1 Liontown Horizon

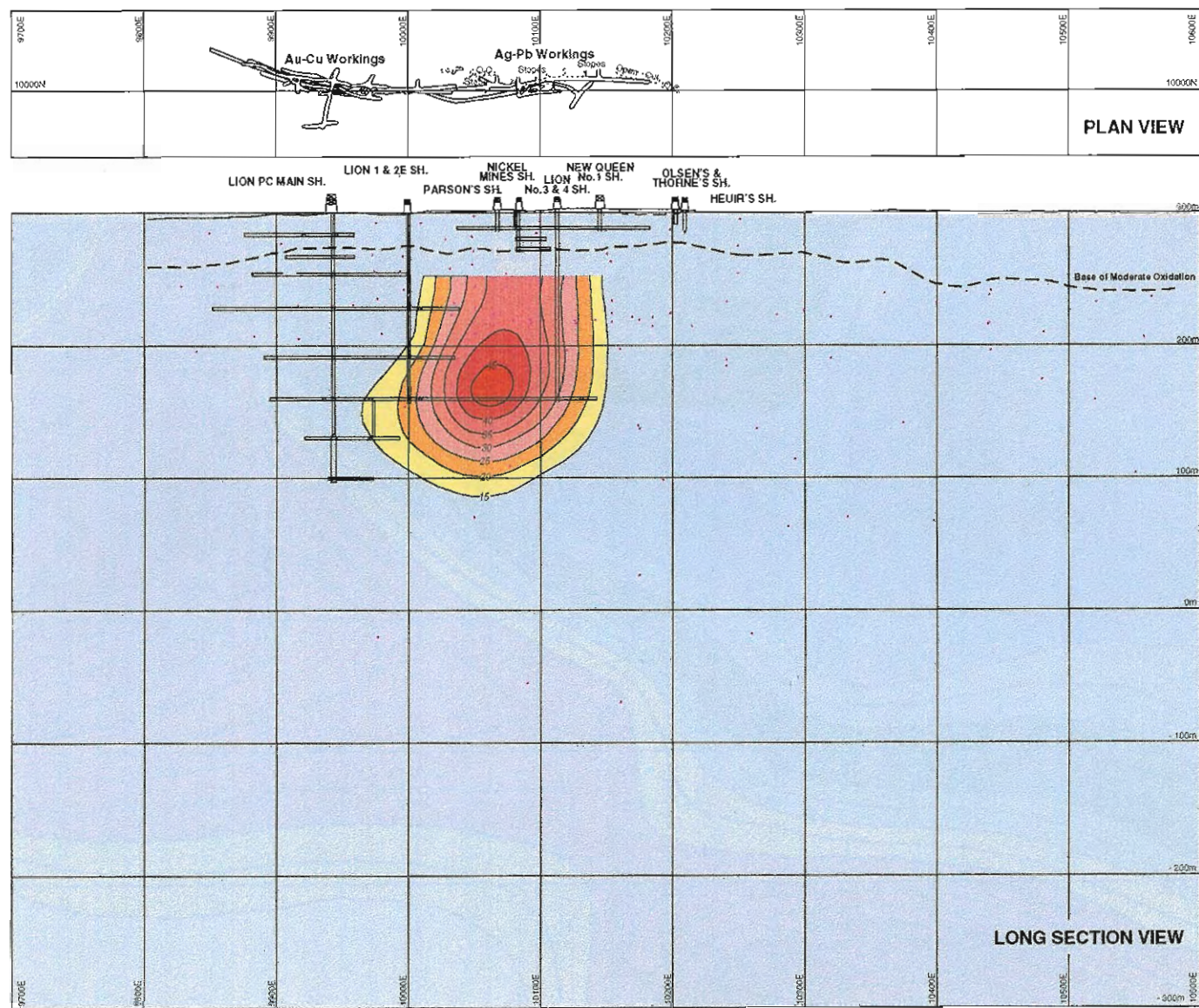
Figure 15 depicts the total zinc metal accumulation in the mineralised portion of the Liontown Horizon. The lead distribution has not been shown but follows that of zinc. The zinc distribution has a "butterfly" geometry and pitches at 70° to the east. The higher grade and thicker lobe occurs between grid lines 9800E and 10100E. This lobe is centred over the Cu-Au stringer system which is essentially mapped out by the workings developed off the Lion PC shaft (Figure 15). Copper metal accumulation contours define a single high located below the Nickel Mines shaft (Figure 16). The Cu high does not coincide precisely with the thickest and highest grade part of the upper lobe though is still broadly coincident with its eastern extension. Unfortunately there is no available structural data on the orientation of the Cu-Au bearing quartz-pyrite stringers from the Lion PC shaft area. Nevertheless it is likely the footwall stringer system drifts across the footwall sequence obliquely from 9900E to 10050E and possibly fed a hydrothermal vent site located below

LIONTOWN HORIZON Zn METAL ACCUMULATION (m%)

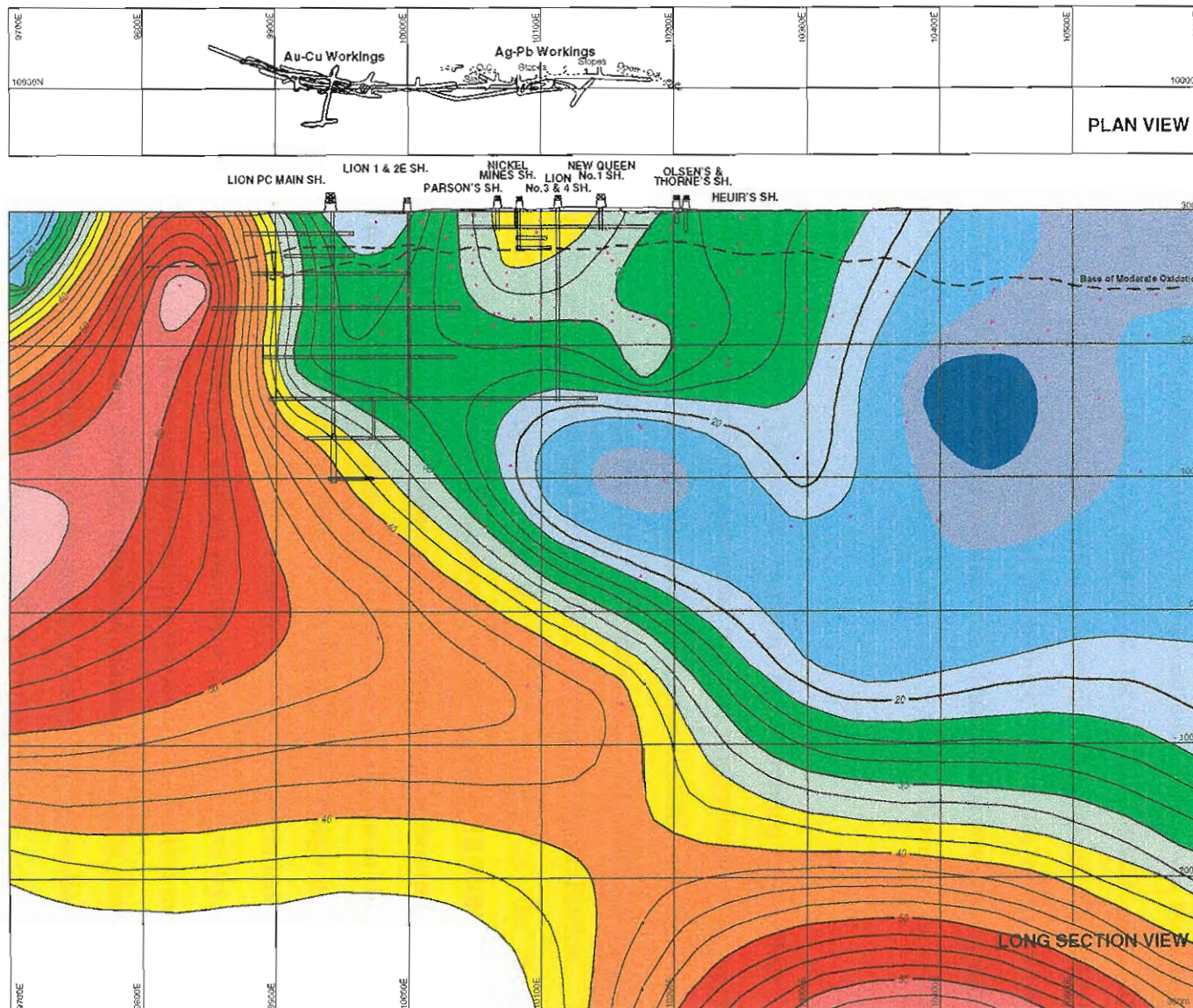


LIONTOWN HORIZON

Cu METAL ACCUMULATION (m%)



LIONTOWN HORIZON ISOPACH MAP (m)

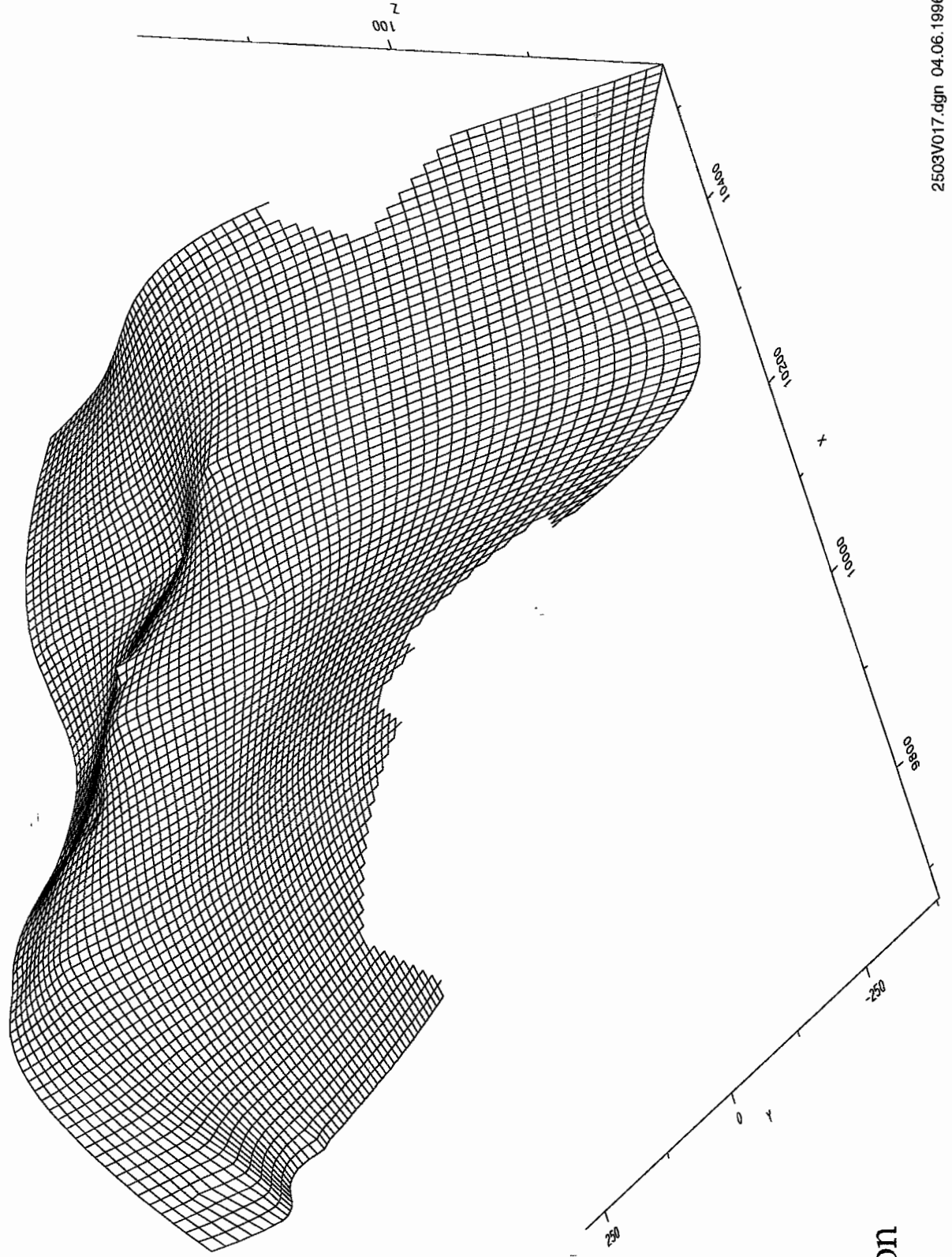


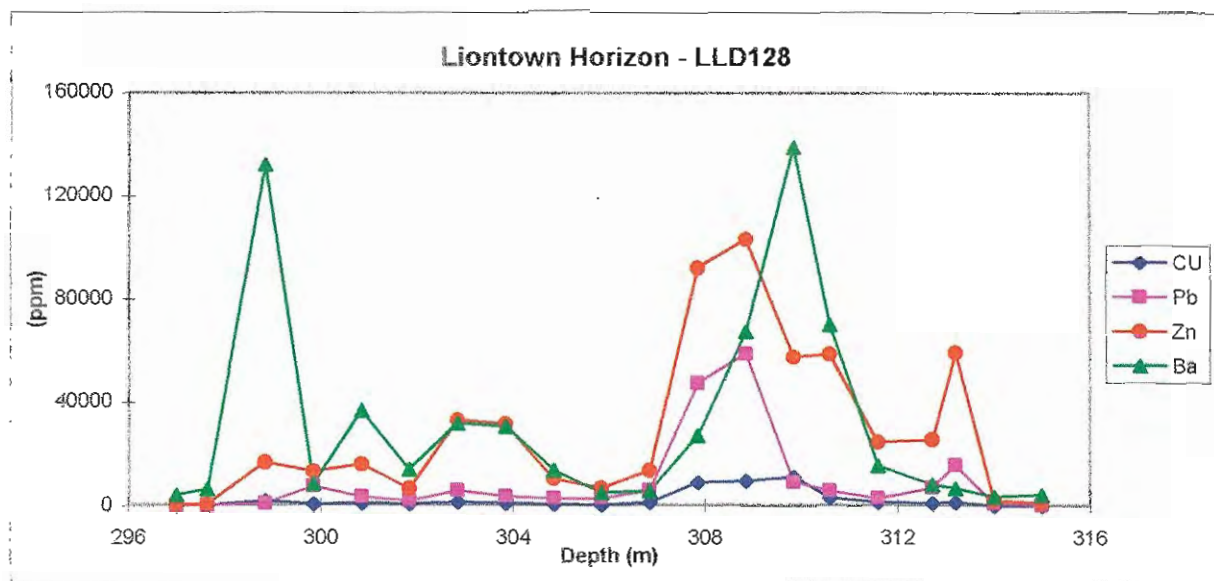
the Cu high on 10060E. The distribution of the historic workings tends to support this suggestion.

To understand the paleotopography of the ancient seafloor during the period of mineralisation, the true thickness of the entire Liontown Horizon was contoured on long section to produce an isopach map (Figure 17). The horizon was taken as the top of the sericitic siltstone package through to the siltstone-pumice breccia interface. In addition a Connolly diagram of the pumice breccia surface was constructed. This was achieved by creating a reference plane 100m below and parallel to the pumice breccia - Liontown Horizon interface. Data points were then created by measuring the perpendicular distance from the reference plane to the upper surface of the pumice breccia. A minimum of 10 points were measured for each 100m spaced cross section. These points were then compiled as an x, y, z file and a 3D net of the pumice breccia surface was produced using Geosoft software.

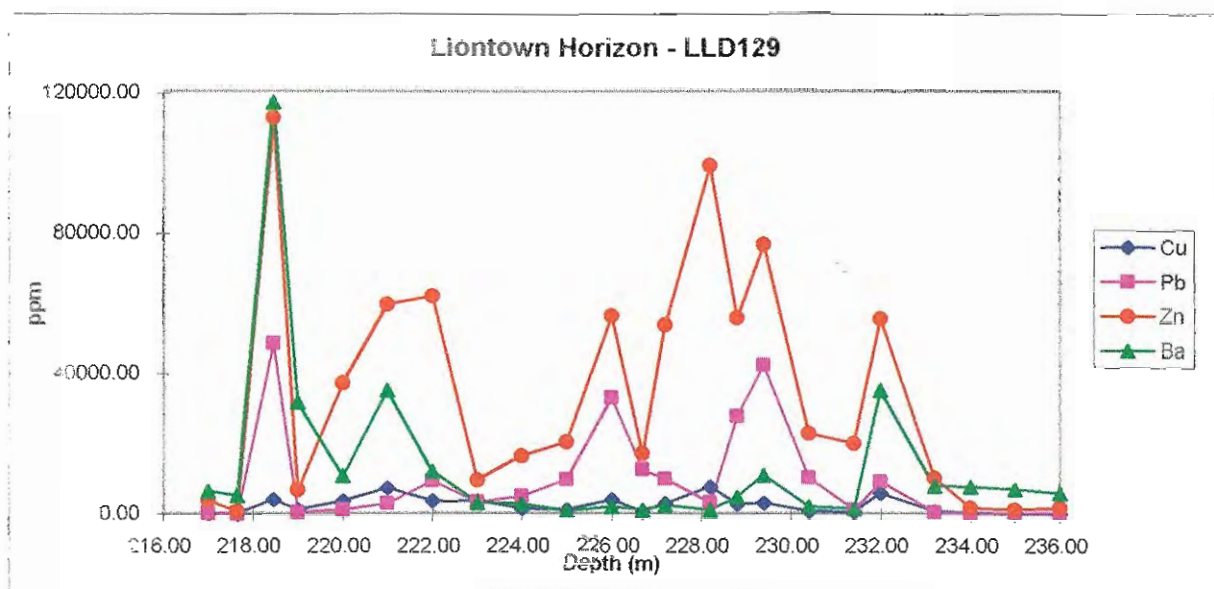
The thickness variation of the Liontown Horizon is interpreted to reflect the paleotopography at the onset of stratiform base metal sulphide mineralisation (Figure 17). There are two relatively thick zones of sediment accumulation at 9,600E and 10,400E with a moderately thick "trough" connecting the two. The eastern zone (10,400E) is related to the growth fault on the same section and is essentially devoid of mineralisation. The stratiform mineralisation is developed along the eastern margin of the western basin/depression. Given the relatively high Cu metal accumulation at 10,060E represents the main base metal feeder zone, then the mineralisation may be interpreted to have moved down slope to the west and the south east into deeper parts of the basin. Fragments of altered siltstone are common in the central carbonate-base metal lode though it is unclear as whether or not these textures are clastic or the result hydrothermal brecciation. Modelling of the pumice breccia surface tends to support the basin geometry shown by the isopach map and shows a "paleo" ridge in the pumice breccia that parallels the eastern margin of the Liontown basin (Figure 18). The primary structural control governing the northwest-southeast trend of the basin is unknown though may be related to a syn-sedimentary fault developed along the basins eastern margin and broadly coinciding with the apparent ridge in the pumice breccia. Similar features have been observed at the Waterloo deposit by Huston (1991). At Waterloo the mineralised basins were shown to deepen to the west and are

LIONTOWN FOOTWALL PALEOTOPOGRAPHY

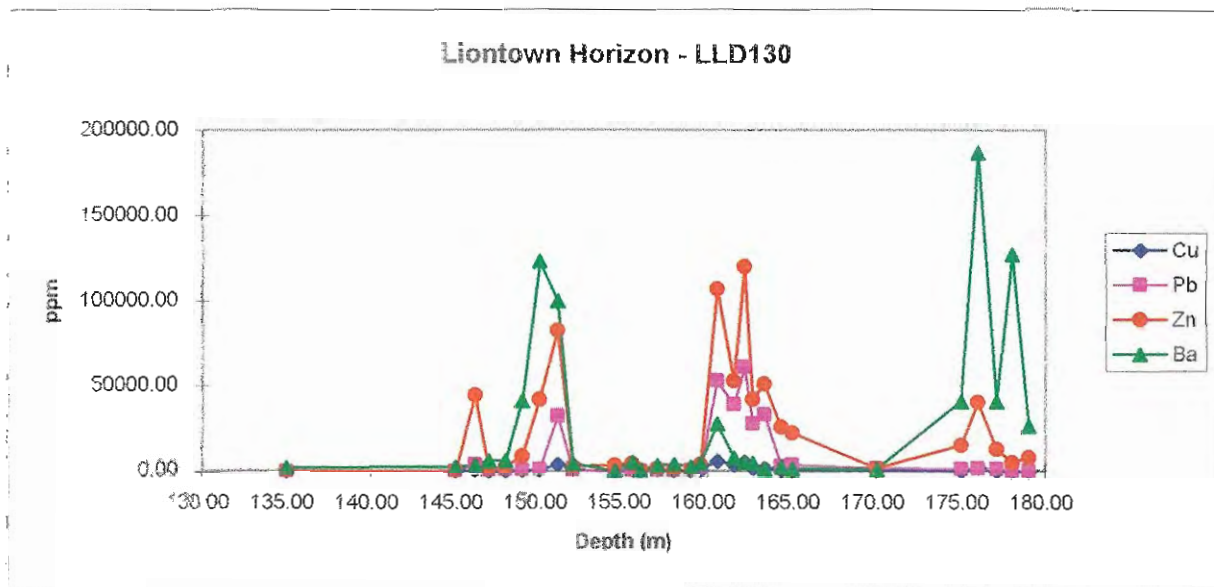




[a]



[b]



[c]

Figure 19: Stratiform mineralisation - Cu,Pb,Zn, & Ba profiles through the Upper, Central and Lower Lodes.

interpreted to be controlled by west dipping, listric growth faults thought to serve as hydrothermal fluid conduits (Huston 1991).

Figure 19 depicts the variation of Cu, Pb, Zn and Ba vertically through the mineralised portion of the Liontown Horizon (top of upper lode to base of lower lode). The data has been sampled from three recently drilled and representative drillholes LLD128 (10200E), LLD129 (10100E) and LLD130 (9900E). The profile for LLD130 defines quite clearly the upper central and lower lodes, whereas in LLD128 and LLD129 the boundary between the central and lower lodes tends to be gradational. Each profile shows strong barium enrichment at the top of the upper lode (<10% Ba), although not shown the baritic cap always has associated elevated gold in the range 0.5 to 1.5g/t Au. The remainder of the barium peaks are related to zones of barite veining or massive carbonate and barite. Copper, although relatively low grade (<0.4%), does show weak enrichment in the central lode on each profile and probably reflects a relative temperature gradient from the central/lower lode through to the less intense and more oxidised upper lode.

Figure 20 shows log-log scattergrams for the same data set used in the construction of profiles for LLD128-130. As expected there is a strong correlation for Pb-Zn and for Cu-Zn. This tends to suggest the base metals have been deposited by similar processes, probably transported as chlorocomplexes and precipitated by either a decrease in temperature or increase pH (Huston, 1991). Gold displays moderate correlations with Ag, Cu, Zn and Ba with Ba the strongest at 0.53. These results may suggest the gold was deposited by both the higher temperature related chlorocomplexes and the lower temperature gold thiocomplexes. Silver only displays a significant correlation with Au, possibly suggesting the presence of electrum.

7.2 Carrington Lode

The distribution of zinc accumulation in the Carrington lode is shown in Figure 21 and illustrates the moderate easterly plunge of the mineralisation. The distribution of lead is essentially the same as for zinc though the high grade lens at 10450E is surprisingly lead poor (Figure 22). The copper distribution has two main zones of concentration within the Carrington lode at 10100E and 10190E and a third subsidiary zone associated with the eastern lens at 10500E (Figure 23). The copper zones at 10100E and 10190E although within the high grade core of the Carrington lode, have no spatial association with a

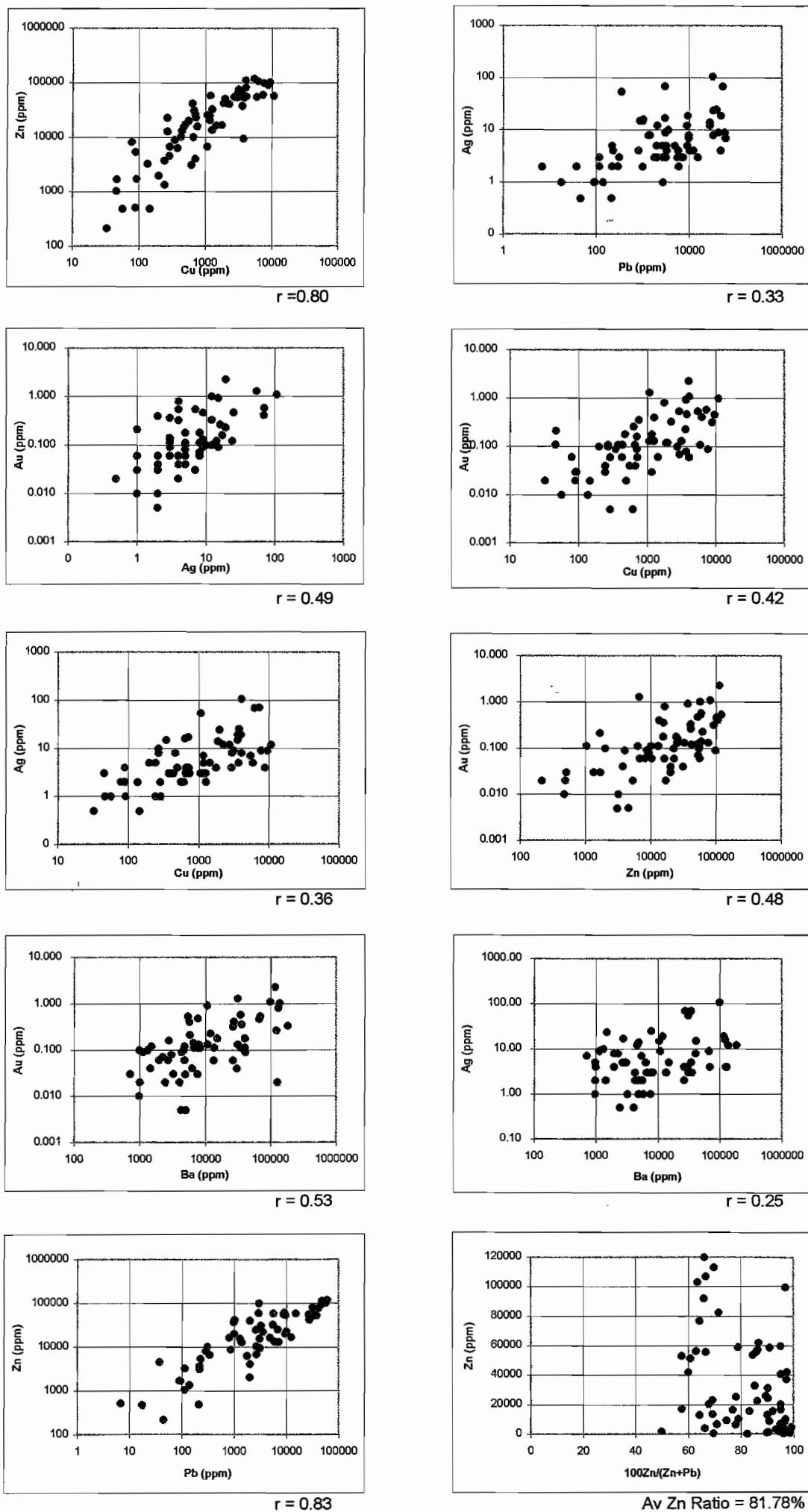
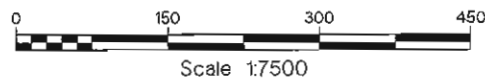
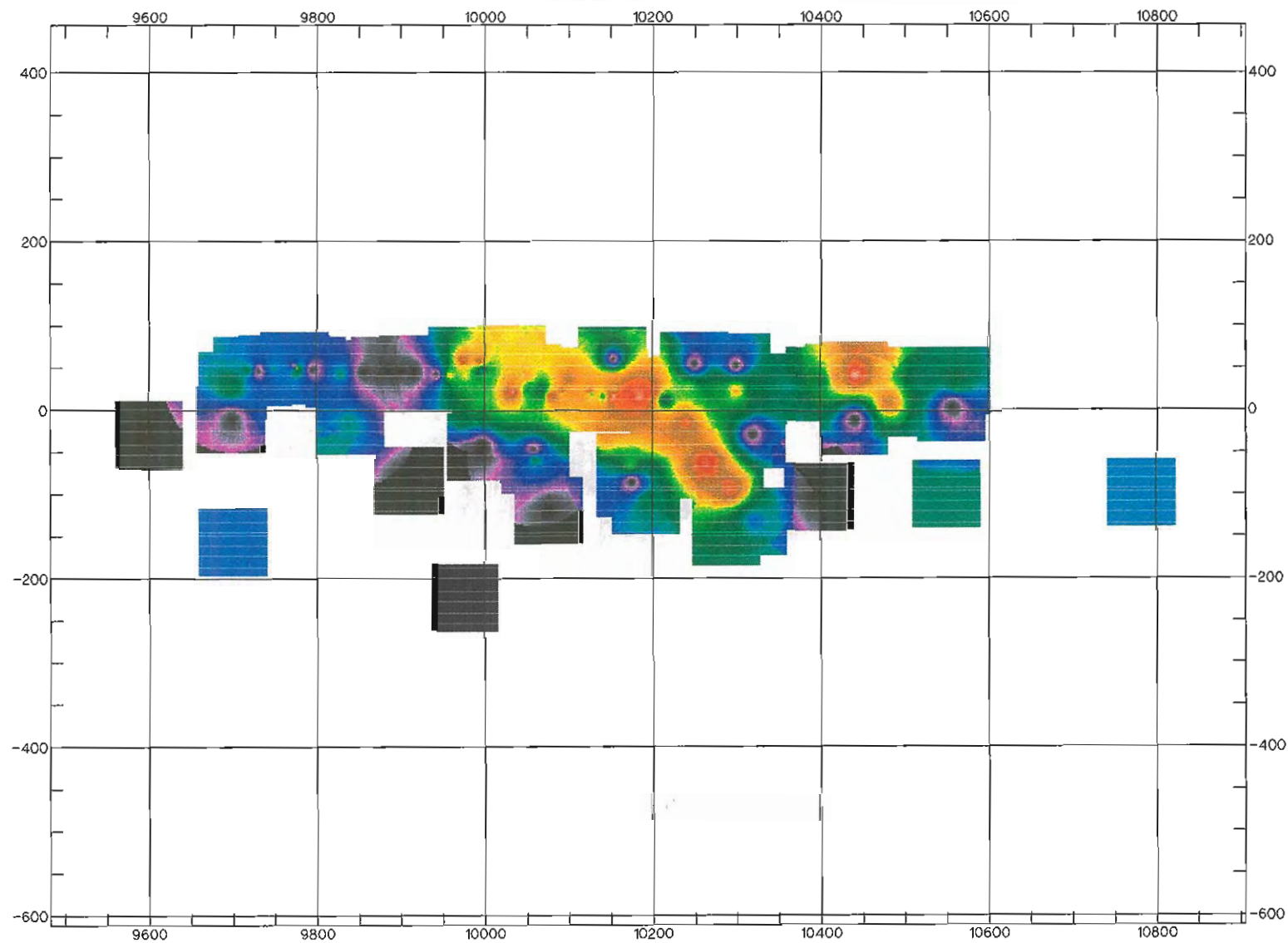


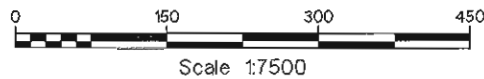
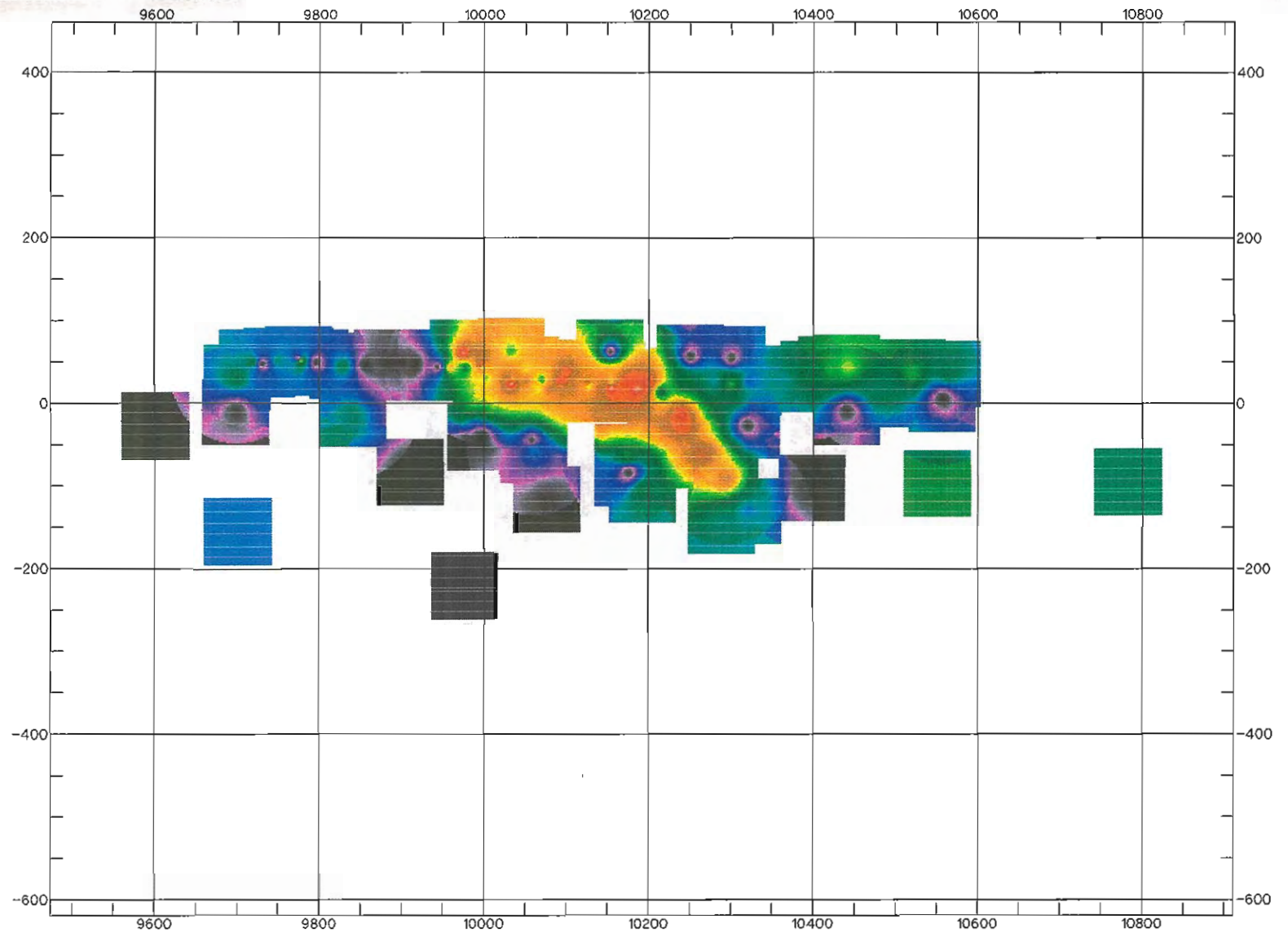
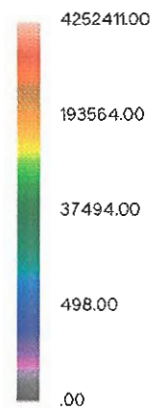
Figure 20: Liontown Horizon Stratiform Mineralisation - Scattergrams showing metal relationships.



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LIONTOWN - Long Section
Carrington Lode
Zn Distribution (m x ppm)

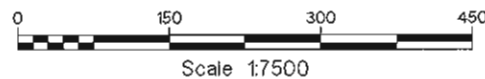
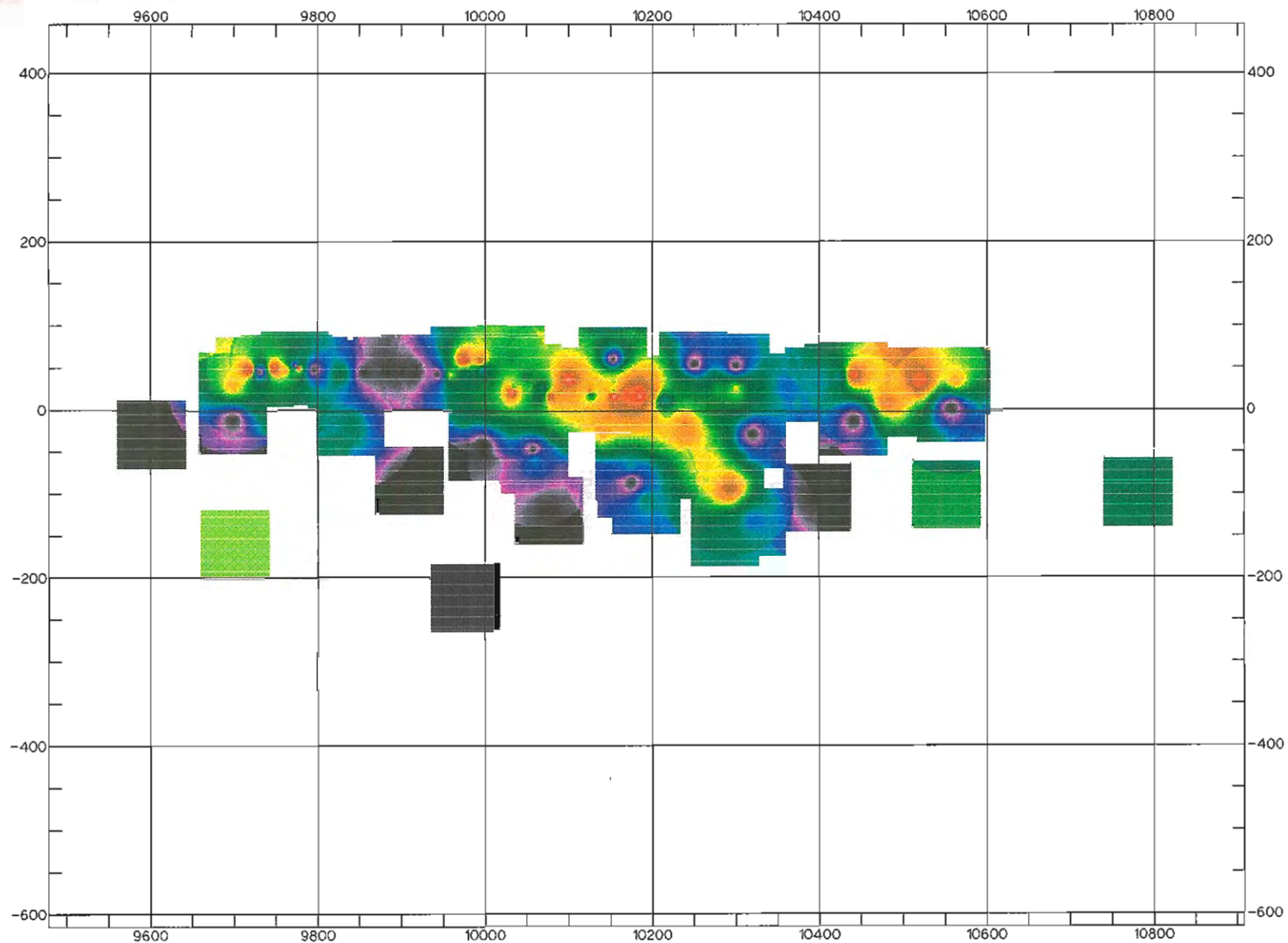
GEO:	SCALE 1:7500	REPORT: Fig 21
DRAWN:	DATE: 12-03-1996	PLAN:



RGC EXPLORATION PTY LTD

LIONTOWN - Long Section
Carrington Lode
Pb Distribution (m x ppm)

GEO:	SCALE 1:7500	REPORT: Fig 22
DRAWN:	DATE: 12-03-1996	PLAN:



RGC EXPLORATION PTY LTD

LIONTOWN - Long Section

Carrington Lode

Cu Distribution (m x ppm)

GEO:	SCALE 1:7500	REPORT: Fig 23
DRAWN:	DATE: 12-03-1996	PLAN:

significant stringer zone. The eastern zone at 10500E has significant copper in the range 1-2% Cu though has undergone fracture controlled supergene enrichment which has distorted the original copper levels. The eastern lens does however appear to be related to a stringer zone located at 10550E, -75RL. The stringer system includes a major quartz-carbonate metre wide stringer carrying 2.07%Cu, 1.59%Pb, 4.96%Zn, 21 g/t Ag and 10.3 g/t Au. This eastern stringer zone in hole LLRC100 also includes 22m @ 1.61 g/t Au from the interval 131-153m.

The Carrington lode between 9980E and 10350E does not appear to have a strong stringer zone located stratigraphically below. The zinc distribution does however coincide with the eastern margin of the copper-gold stringer system centred on 9900E. Given the absence of a significant stringer zone below the Carrington lode and in accordance with the interpretation of this study that the Carrington lode is a sub seafloor replacement system controlled by the lateral migration/circulation of hydrothermal fluids through permeable volcanoclastic horizons. Then it seems reasonable to suggest the mineralising fluids were derived from the same stringer zone that fed the stratiform lodes and at some stage during the systems evolution the hydrothermal fluids are thought to have been tapped off the main stringer zone and channelled to the east along the permeable feldspar phytic and now chloritic volcanoclastic schist unit.

Figure 24 provides a series of log-log scattergrams for the Carrington lode. In contrast with the stratiform mineralisation Ag-Pb and Ag-Cu show moderate to strong correlations and may reflect a greater proportion of Ag resident in tennantite and galena. Gold is best correlated with Cu though has only a weak correlation coefficient of 0.37. However, if zinc values exceeding 1% are plotted against their respective gold grades, it then becomes apparent there is a strong correlation between zinc and gold. Figure 25 shows the vertical distribution of Cu, Pb, Zn and Ba through the Carrington Lode and emphasises the extremely high grade cap (>20% Zn) routinely developed at the top of the lode. Lead shows a sympathetic relationship with zinc, copper and barium are consistently low with little variation.

The stratiform lodes and the Carrington lode at Liontown have similar zinc ratios averaging 82 and 83 respectively. The values are just outside the range for 'typical' Tasmanian VHMS deposits (60-77) though within the range of 60-88 for the Mount Windsors VHMS systems.

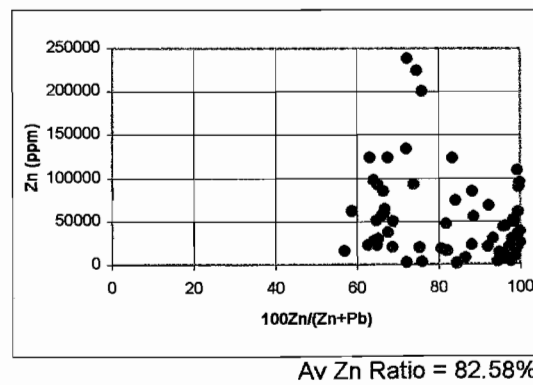
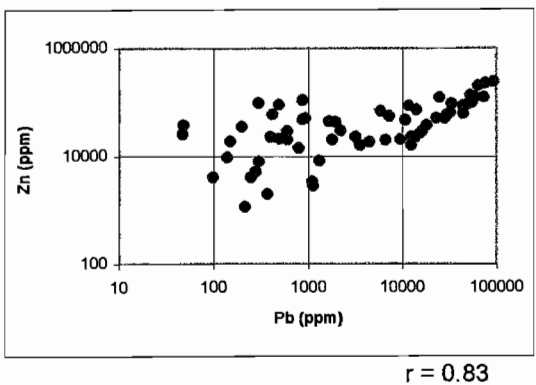
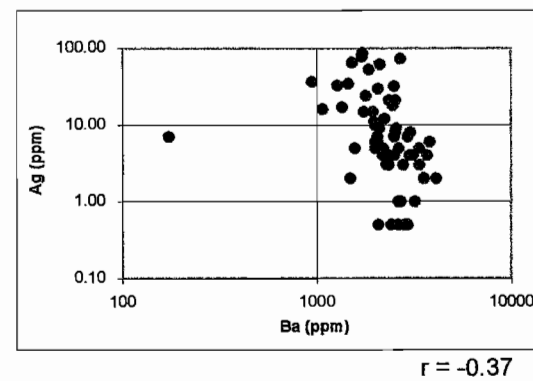
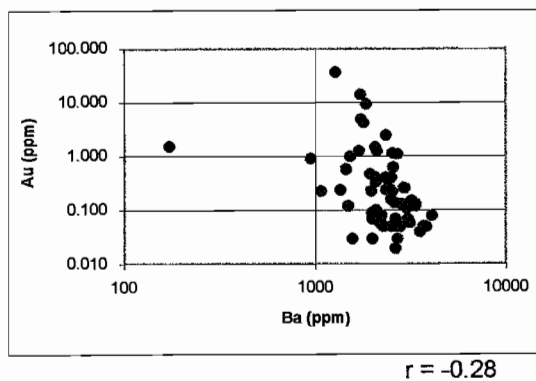
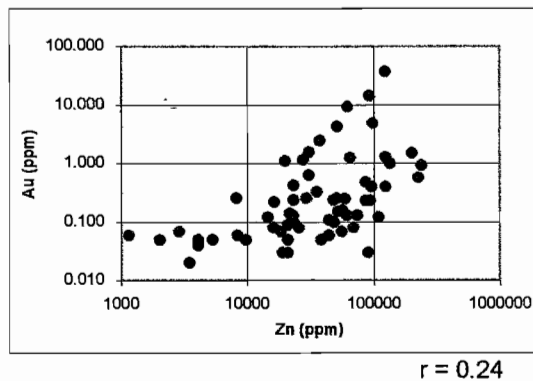
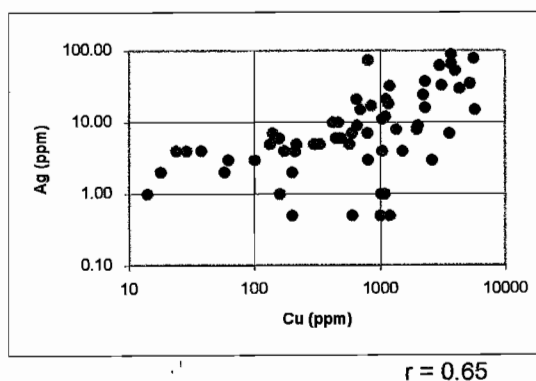
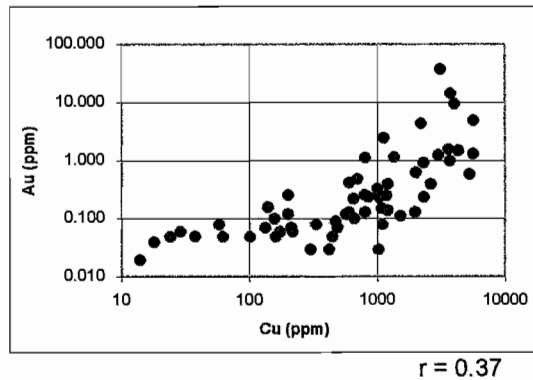
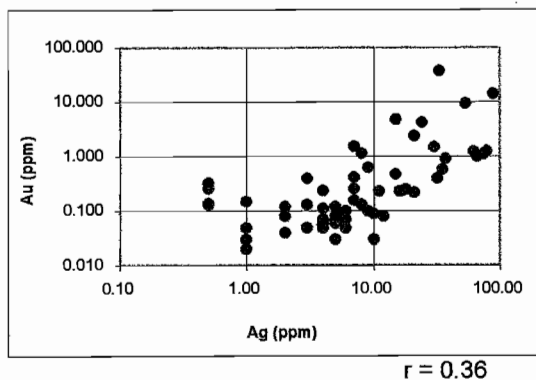
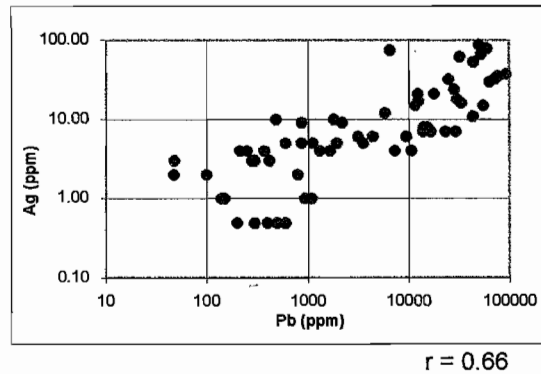
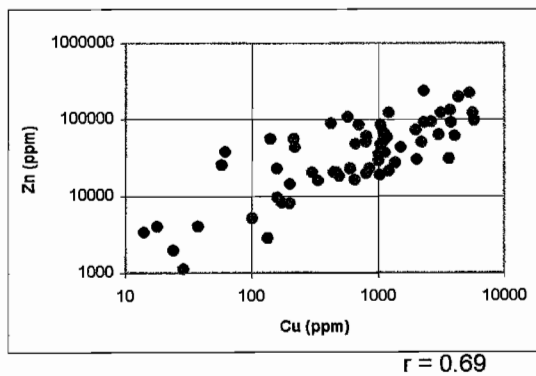


Figure 24: Carrington lode - Scattergrams showing metal relationships.

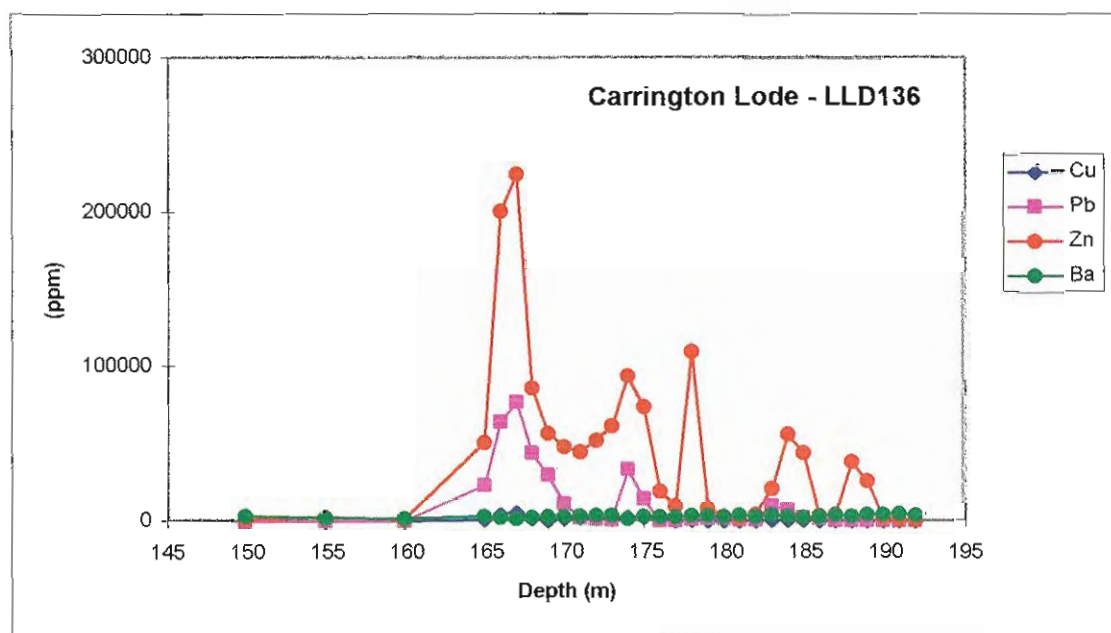
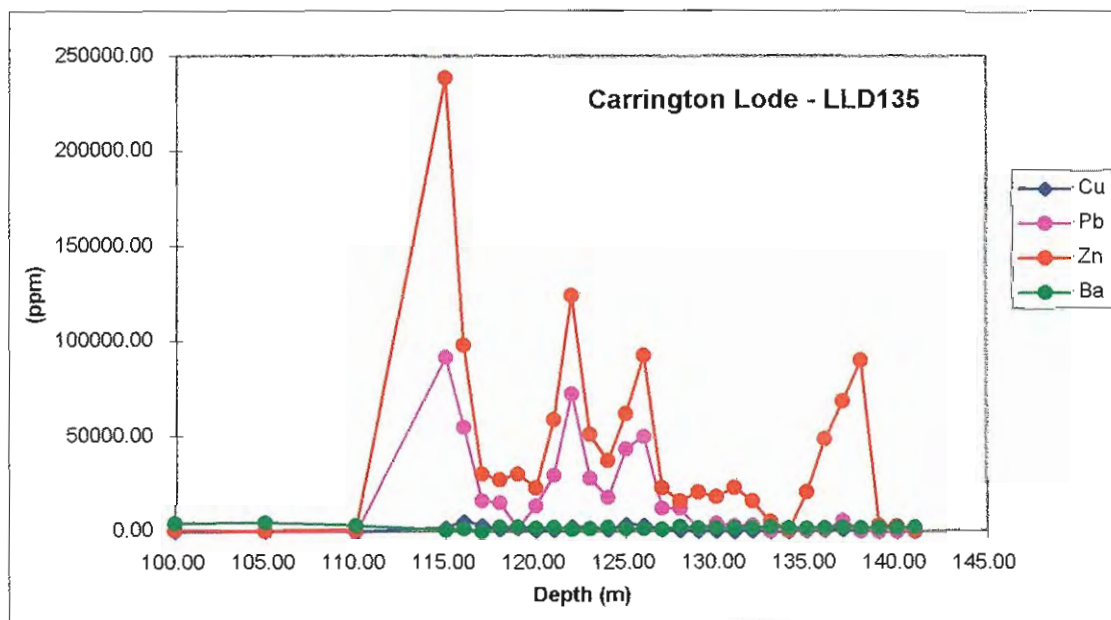


Figure 25: Carrington Lode - Cu,Pb,Zn & Ba profiles through orebody.

Huston (1991) calculated a zinc ratio of 88 for the nearby though stratigraphically lower Waterloo deposit. He interpreted the ratio as having been controlled by lead poor andesitic source rocks and by inference implies significant leaching of the footwall stratigraphy was unlikely to have extended beyond the known extent of the underlying andesitic lithologies, that is 300m below the ore horizon. At Liontown there are no known andesitic rocks in the footwall and yet the zinc ratio is at the higher end of the spectrum. Low temperature fluids ~150-200 °C as modelled by Huston and Large (1987) and dacitic source rocks are the most likely controlling factors governing the Liontown zinc ratio.

8.0 ISOTOPE GEOCHEMISTRY

Numerous studies undertaken in Japan and Canada using oxygen isotopes analyses show a consistent relationship between VHMS alteration zones and $\delta^{18}\text{O}$ values of whole rocks. Green et al (1983) documented concentric zoning patterns of the whole-rock $\delta^{18}\text{O}$ values and of alteration minerals in the footwall volcanics around the Fukazawa Kuroko deposit. The $\delta^{18}\text{O}$ values of the whole rocks were shown to gradually increase from less than 8 per mil in the central sericite-chlorite zone that extends about 0.5 km outside of the ore zone, to 8 to 14 per mil in the montmorillonite zone, a 1 to 3 km wide zone occurring outside the sericite-chlorite zone, to mostly greater than 14 per mil in the peripheral zeolite zone (Green et al, 1983). These results suggest that whole-rock $\delta^{18}\text{O}$ values are potentially useful in VHMS exploration and have the added benefit of being more resistant to modification by regional metamorphism than the primary alteration assemblages. The $\delta^{18}\text{O}$ values and their correlation with the alteration zonation is interpreted as a result of interaction between the footwall rocks and modified seawater at different temperatures (Green et al, 1983).

At Liontown the altered footwall rocks have been delineated by drilling over a strike length of 7-8 kms. These rocks are generally blanketed by up to 60 metres of Tertiary overburden and are not amenable to conventional mapping and surface geochemical exploration techniques. To assist in identifying the more prospective portions of the defined alteration system a programme of $\delta^{18}\text{O}$ whole-rock sampling was undertaken. Results of a similar study carried out at Thalanga by M.Jones and S.Halley and are included for comparison. The Thalanga samples were collected by M.Jones from the upper 10 metres of the footwall

ryholite and from the base of the quartz eye volcanoclastic unit (ore horizon). The results of the Thalanga study have not been previously documented (Appendix, Table 8).

8.1 Lateral Variation of $\delta^{18}\text{O}$ Whole-Rock Values

The Liontown sampling programme was designed to specifically sample the altered footwall pumice breccia and where possible, specimens were consistently collected from within 5-30 metres below the Liontown Horizon-pumice breccia contact. In total 28 whole-rock samples were analysed across the footwall alteration system over a distance of 7.4 kms between 7600E and 15000E. Samples LLRC107,109,112,115 and 116 have a degree of uncertainty over their accuracy due to contamination in the University of Tasmania isotope line during the first half of 1996. These samples cover the area east of the Liontown deposit between 11100E and 14000E.

The samples were all collected from either drillcore or reverse circulation drill chips. Sample selection was done on a rigorous basis and every effort was made to preferentially sample material dominated by silica alteration as opposed to polymineralic alteration assemblages. Care was taken to avoid,

- (a) Samples with quartz phenocrysts: quartz phenocrysts are resistant to isotopic exchange and distort the hydrothermal signature.
- (b) High pyrite samples (>3%) : Pyrite reacts with BrF_2 to form SF_6 and the consumption of BrF_5 by this reaction can lead to incomplete digestion of the silicates.
- (c) Samples with excessive carbonates (>3%) : carbonates induce odd reactions that can distort the final $\delta^{18}\text{O}$ value.

Prior to analysis all samples were first checked with qualitative XRD-mineralogy to ensure sample quality and consistency was maintained. The qualitative XRD was undertaken in the Department of Geology, University Tasmania. The XRD results provide major, minor and

trace phase mineralogy. From these results samples with excessive pyrite and carbonate or samples not dominated by silica alteration could be identified and if necessary discarded.

The digestion of samples and liberation of O_2 was performed at the Department of Geology, University of Tasmania. Finely powdered samples were reacted with BrF_5 at $\sim 600^\circ C$, the liberated O_2 was converted to CO_2 and the isotope analysis completed using a VG Micromass 602D mass spectrometer in the Central Science Laboratory, University of Tasmania. All oxygen isotope analyses are of whole rock samples and are reported as per mil deviation from the SMOW standard (Appendix, Table 8).

Oxygen isotope studies generally involve two variables, the isotopic composition of the fluid and temperature, and there is usually only one constraint, the oxygen isotope ratio measured in a particular mineral. A quantitative assessment of the data cannot be made without an additional constraint or source of data relating to temperature or fluid composition. Analysing a whole rock sample rather than a mono-mineralic sample introduces an extra degree of variability to the interpretation of the results. This was a weakness in many of the studies of the 1980's. It can be overcome by using a quantitative mineral analysis. This is a service provided by Amdel Limited, Adelaide, who use XRD to determine the mineralogy of a sample and match this with a whole rock ICP-AES analysis to quantitatively determine the proportions of each mineral. This procedure was carried out on the samples from Liontown and Thalanga and all data is provided in Table 8 of the Appendix.

Once the mineralogy has been determined, there are two ways to treat the data; (1) calculate the relative temperature of formation, or (2) convert the whole rock $\delta^{18}O$ values to equivalent quartz $\delta^{18}O$ (or other mono-mineralic $\delta^{18}O$). In this study the first option was chosen.

The calculation of the relative temperature estimates is based on two broad assumptions;

- (1) $\delta^{18}O$ of the circulating Cambro-Ordovician seawater is 0‰ (NB this number can be varied in accordance with fluid inclusion data that may provide better estimates) and

- (2) The isotope signature of the hydrothermal fluid remains constant.

The second assumption is implicit, even when simply comparing raw $\delta^{18}\text{O}$ values. In this case, assuming a fluid composition will lead to an unknown amount of error, but the important thing to consider is the relative difference in calculated temperatures between samples. Making these two assumptions does not weaken the interpretation.

In equation (1) $R_{\text{H}_2\text{O}}$ is assigned the value of 0‰ representing Cambro-Ordovician seawater. Thus in this example $\Delta_{\text{qtz-H}_2\text{O}}$ is equal to R_{qtz} , and therefore equal to the whole rock $\delta^{18}\text{O}$ value.

$$\Delta_{\text{qtz-H}_2\text{O}} = R_{\text{qtz}} - R_{\text{H}_2\text{O}} = A(10^6 T^{-2}) + B \quad (1)$$

Assuming an $R_{\text{H}_2\text{O}}$ value of 0‰ and also assuming the whole-rock sample comprised of essentially 100% hydrothermal silica (qtz) then equation (1) could be resolved to provide a relative temperature estimate. If however the samples from any given study have varying abundances of mineral phases then equation (1) can be modified to account for the mineral-water fractionation of the various phases present. The following example documents the equation used in this study and assumes a whole rock sample comprising 70% hydrothermal silica, 20% *chlorite* and 10% *sericite*.
sericite *chlorite*

$$\Delta_{\text{rock-H}_2\text{O}} = 0.7 [A(10^6 T^{-2}) + B]_{\text{qtz}} + 0.2 [A(10^6 T^{-2}) + B]_{\text{ser}} + 0.1 [A(10^6 T^{-2}) + B]_{\text{chl}} \quad (2)$$

$$\Delta_{\text{rock-H}_2\text{O}} = \sum P_i \{A_i(10^6 T^{-2}) + B_i\} = \text{WR } \delta^{18}\text{O} \quad (3)$$

$$10^6 T^{-2} = \frac{\text{WR } \delta^{18}\text{O} - \sum (P_i \times B_i)}{\sum (P_i \times A_i)} \quad (4)$$

where: $\text{WR } \delta^{18}\text{O}$ = The whole $\delta^{18}\text{O}$ per mil value.

P_i = Proportion of mineral i.

A_i & B_i = Fractionation factors for mineral i-water.

$T_{(\text{K})}$ = Temperature in degrees Kelvin.

The mineral-water fractionation factors used in this study are:

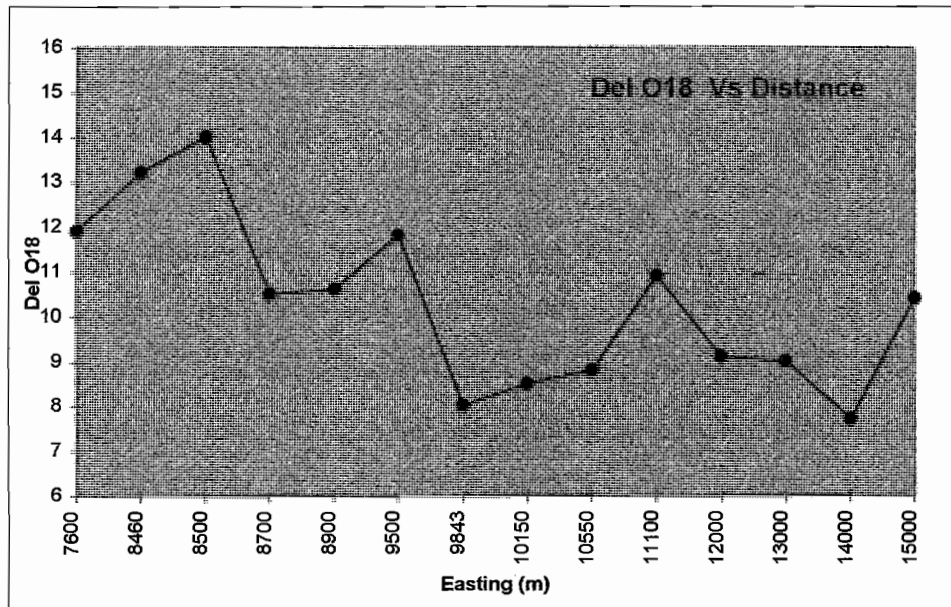
Mineral	A	B	Reference
quartz	3.38	-2.90	Clayton et al, (1972)
sericite	2.38	-3.89	O'Neil and Taylor, (1969)
calcite	2.78	-2.89	O'Neil et al, (1969)
feldspar(ab,kfs)	2.91	-3.41	O'Neil and Taylor, (1967)
chlorite	1.69	-2.57	Wenner and Taylor, (1971)

Results and Interpretation

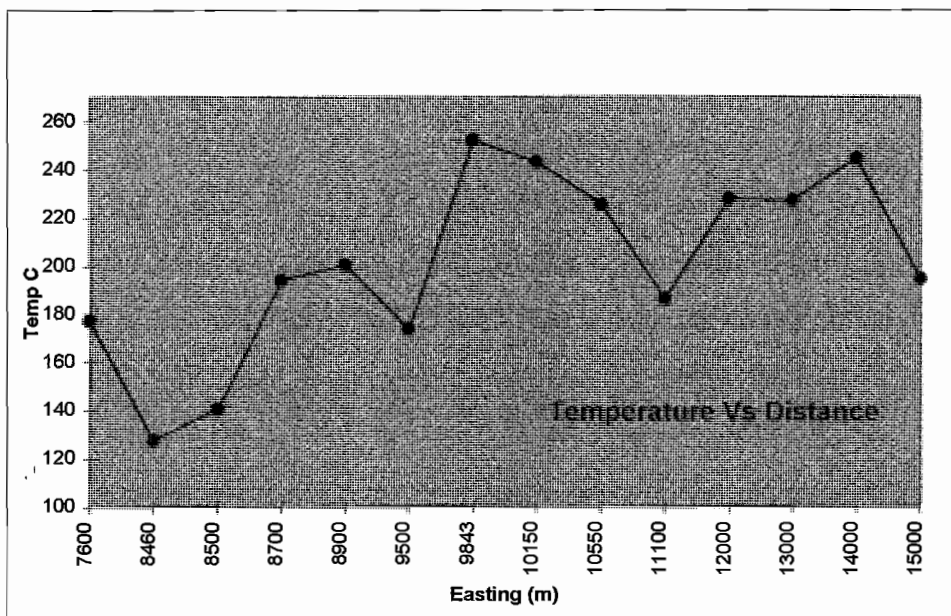
The $\delta^{18}\text{O}$ values of the 28 whole-rock samples taken along the Liontown footwall alteration system range from 7.7 to 15.4 per mil, samples from the Leopardtown system are in the range 6.7 to 10.8 per mil (Appendix, Table 8).

Figure 26a shows the raw $\delta^{18}\text{O}$ whole-rock values as a profile along the footwall alteration system and Figure 26b the corresponding relative temperature estimates. The centre of the Liontown deposit is located at 9900E, Tigertown at 8500E and the Panthertown stringer system at 13000E. The low $\delta^{18}\text{O}$ values in the centre of Figure 26a coincide with the immediate alteration system below the Liontown deposit between 9843E and 10550E. The $\delta^{18}\text{O}$ values below Liontown in the top 5-30 metres of the footwall pumice breccia range from 8.0 to 8.8 per mil and relative temperatures estimates 225° to 252°C.

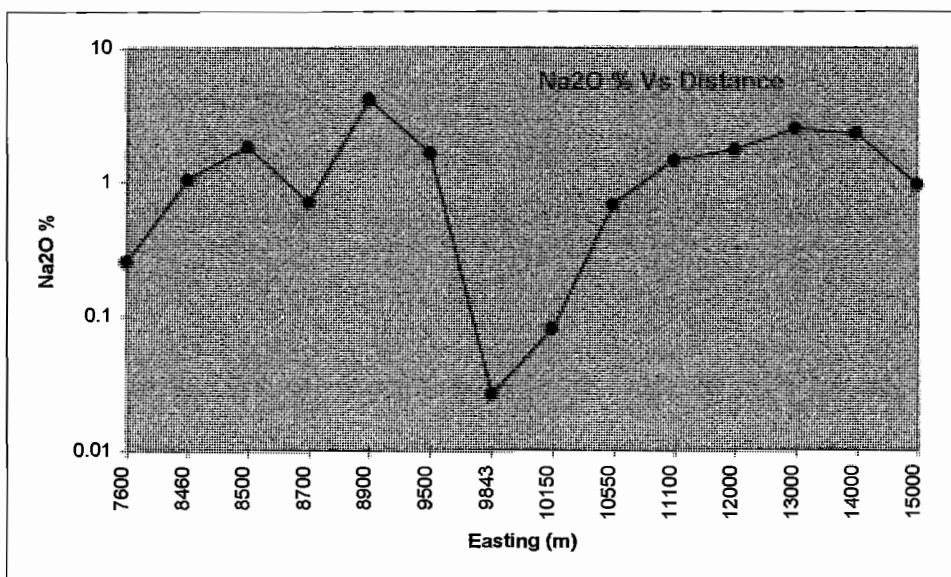
At Tigertown the $\delta^{18}\text{O}$ values are considerably higher than for Liontown and range from 12.8 to 15.4‰ giving an average of 14.2 per mil. The relative temperature estimate for Tigertown is 140°C and is in accordance with the weakly altered and oxidised appearance of the associated footwall alteration and may suggest the system was most likely a low temperature hydrothermal centre. Deep within the footwall approximately 200m stratigraphically below the Tigertown exhalative mineralisation, the weak Cougartown stringer system reports a $\delta^{18}\text{O}$ whole-rock value of 15.3‰ from feldspar phyric silicified pumice breccia with a calculated feldspar content of 33%. Although no specific attempt was made to characterise the $\delta^{18}\text{O}$ whole-rock signature of the unaltered dacitic pumice breccias, this result from deep within the Cougartown pumice breccia sequence should provide a



[a] Cougartown **Liontown** Panthertown



[b]



[c]

Figure 26: Del O18, Relative temperature estimates, and Na2O% variation along the Liontown footwall alteration system.

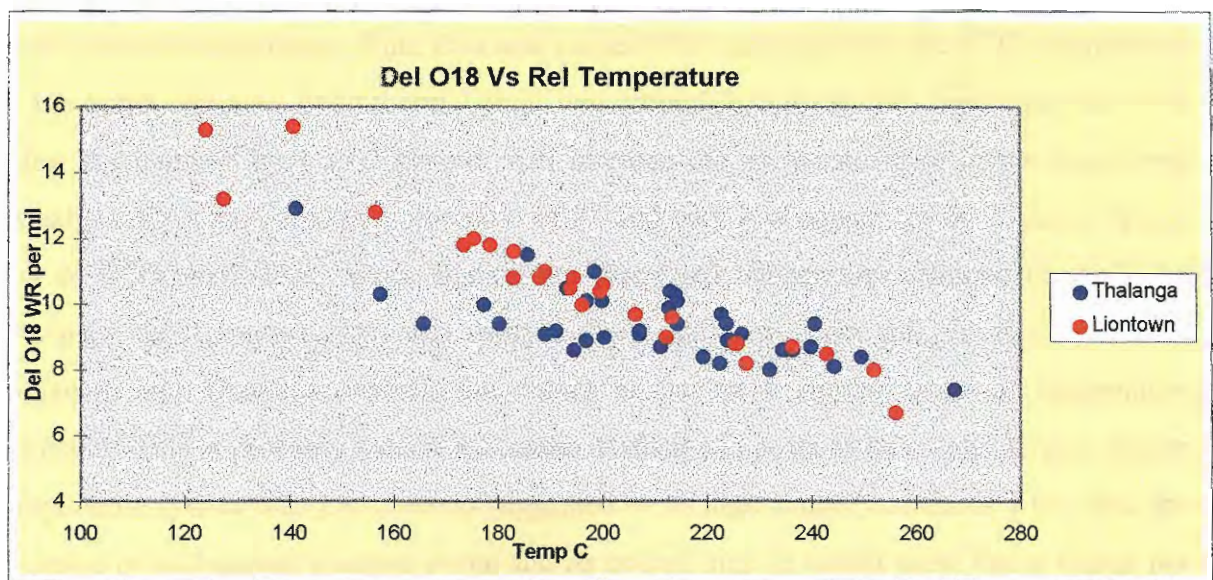
$\delta^{18}\text{O}$ whole-rock value close to the primary value. Clearly there is a strong contrast in $\delta^{18}\text{O}$ values between Liontown and the relatively unaltered dacitic pumice breccia at Cougartown.

Figure 26b also shows a second zone of elevated temperature estimates at 13,000 - 14,000E. The area is associated with a recently discovered pyrite \pm chalcopyrite, carbonate-barite stringer system known as Panthertown. The stringer system on section 13,000E is of moderate intensity, though appears to be relatively localised. In this case it appears low $\delta^{18}\text{O}$ whole-rock values can again be shown to have a direct relationship with a hydrothermal centre. The Panthertown system has since been shown by drilling to have little potential for the discovery of exhalative massive sulphide. Despite the absence of economic mineralisation at Panthertown it does appear that the whole rock oxygen isotope data and temperature estimates do provide a vector to zones of increasing alteration intensity \pm mineralisation.

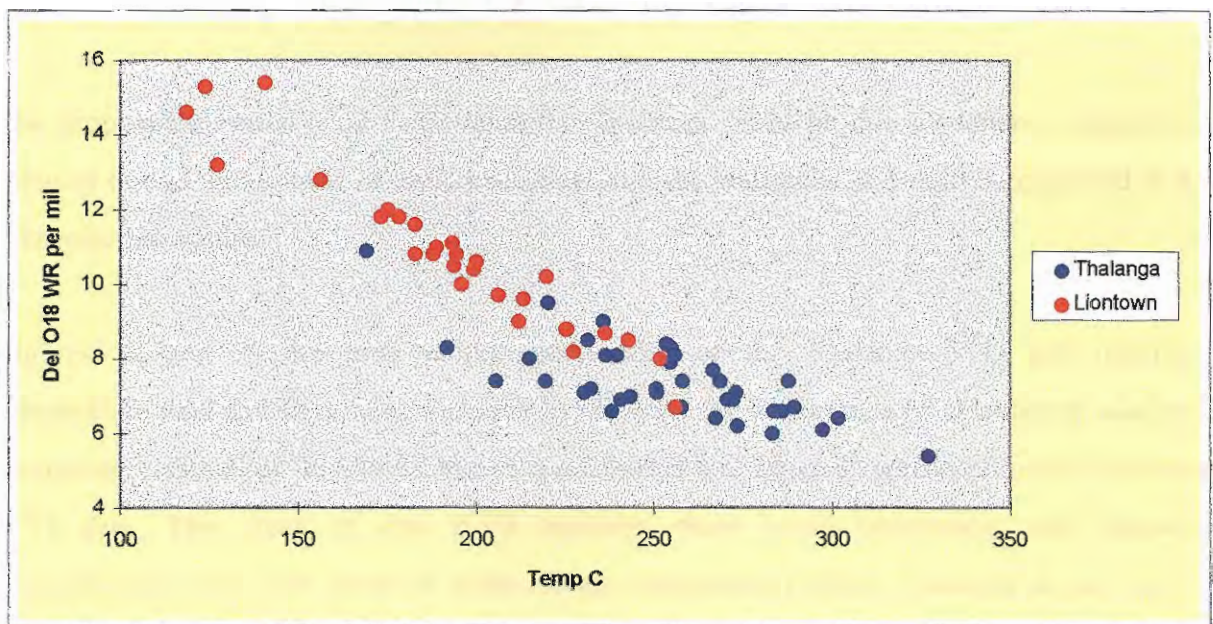
It should also be pointed out that the high temperature estimate on line 14000E has been calculated from a sample comprising 26% carbonate. As a result the temperature estimate is considered unreliable and should be viewed with caution. Given the nature and intensity of the alteration at 14000E, the temperature calculation is probably an over estimation.

Figure 26c illustrates the corresponding $\text{Na}_2\text{O}\%$ data for the whole-rock profile and quite clearly shows significant sodium depletion in the immediate footwall of the Liontown deposit. This is not the case for Tigertown and Panthertown. Although the $\delta^{18}\text{O}$ whole-rock values and temperature estimates have identified Panthertown as a potential hydrothermal centre of elevated temperature, the high $\text{Na}_2\text{O}\%$ data tends to discriminate between it and Liontown. From this example it can be seen the $\delta^{18}\text{O}$ data is providing vectoring toward higher temperature hydrothermal centres, though these do not always equate with mineralisation and that the isotope data must be used in conjunction with other geological and geochemical data.

By using an assumed seawater/hydrothermal fluid value of zero per mil, the calculated temperature estimates for the Liontown deposit are between 225° to 252°C. The assumption of a 0 per mil fluid is likely to underestimate the temperature. Water-rock reactions, particularly at higher temperatures where reaction rates are faster, will increase the fluid



(a) Lontown & Thalanga assumed seawater/hydrothermal fluid value = 0 per mil
 $r = -0.87$



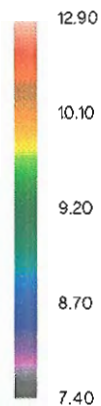
(b) Assumed seawater/hydrothermal fluid values: Lontown 0 per mil
 Thalanga 2 per mil

Figure 27: Lontown and Thalanga del O 18WR Vs relative temp using various assumed seawater/hydrothermal fluid values.

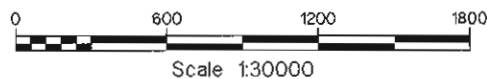
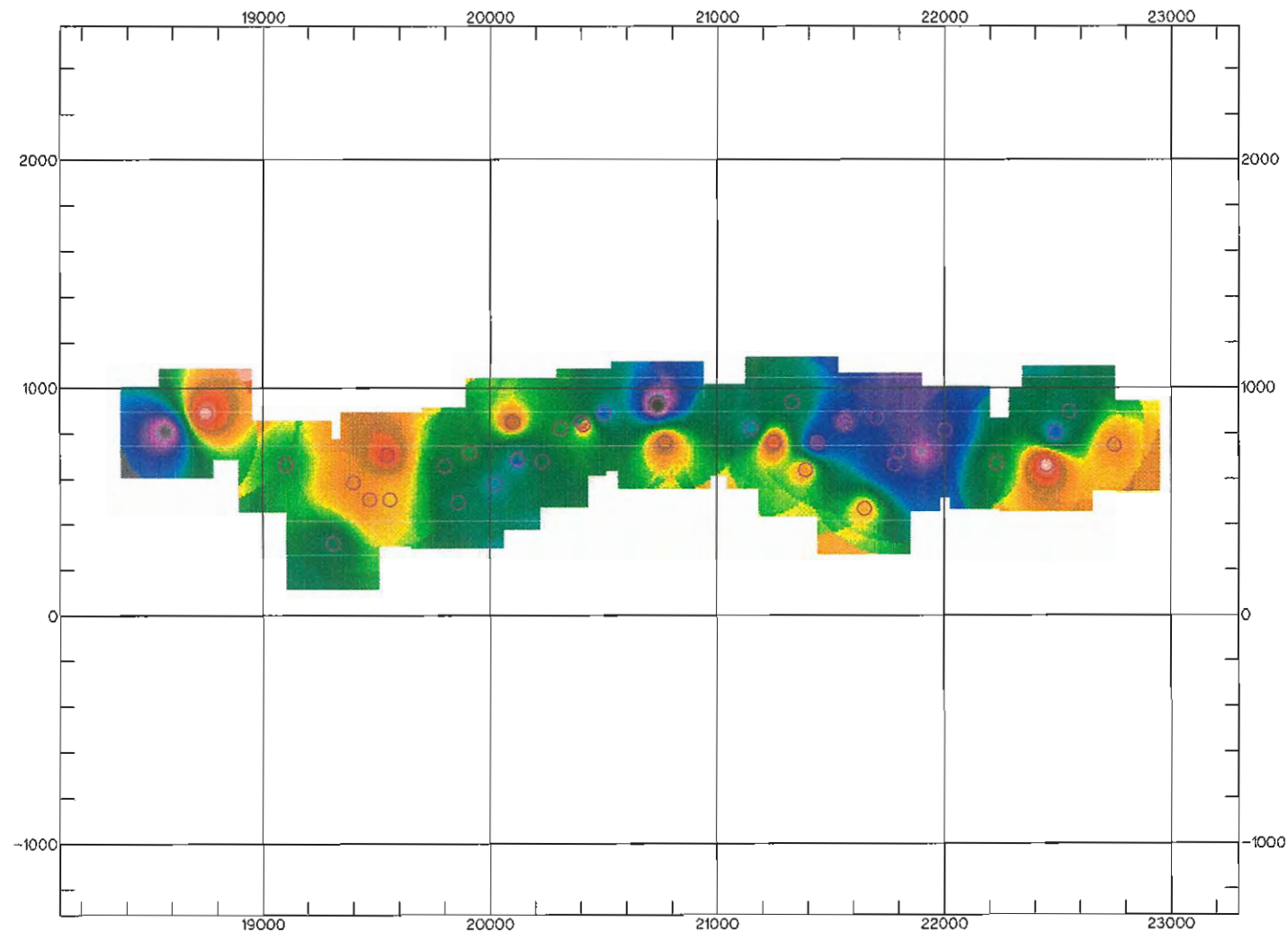
$\delta^{18}\text{O}$ above the 0 per mil value of seawater. Pisutha-Arnond and Ohmoto(1983) reported $\delta^{18}\text{O}$ values of -6 to +4 per mil for Kuroko fluids estimated from the analyses of quartz and fluid inclusion temperature. Khin Zaw and Large(1992) estimated that the $\delta^{18}\text{O}$ composition of the South Hercules hydrothermal fluid was around 2 to 4 per mil. Increasing the fluid value at Liontown by 1 to 2 per mil will increase the temperatures to levels considered unrealistic for a system with a zinc ratio of 82 and very low copper levels. Figure 27a is a plot of $\delta^{18}\text{O}$ whole-rock values against the calculated temperature estimate for both the Thalanga and Liontown data sets using a fluid value of 0 per mil. In this figure the Liontown and Thalanga deposits are shown as having a similar range of temperature estimates. This is probably incorrect because Thalanga appears to be a considerably higher temperature system than Liontown as suggested by its high copper content of 1 to 1.8%, the presence of widespread massive pyrite and its overall size. It would seem that a higher per mil fluid value of between 2-4 is more appropriate for Thalanga. Figure 27b plots the Thalanga isotope data and temperature estimates using a fluid value of 2 per mil. The fluid per mil value of 0‰ used for Liontown is therefore considered a little high and the original value was probably in the range -2 to 0 per mil.

The proposed elevated $\delta^{18}\text{O}$ fluid value for Thalanga could be due to either a magmatic input or due to widespread isotopic exchange with the wallrocks as would be expected in a relatively hot system.

Figures 28 and 29 are long section projections of the Thalanga $\delta^{18}\text{O}$ and relative temperature data and have been included to illustrate the importance of calculating relative temperature estimates. Figure 28 shows a contoured and imaged representation of the raw $\delta^{18}\text{O}$ data. The areas of low $\delta^{18}\text{O}$ numbers show some correlation with known mineralisation and with areas of more intense alteration. Central Thalanga is the more pyritic and copper rich orebody and is centred at 20600E. East Thalanga is the second most significant mineralised centre and is located at 21800E. Both orebodies are considered to be associated with major hydrothermal vent sites and each have a strongly developed pyritic stringer zone. Central Thalanga and East Thalanga are generally thought to be centres of elevated temperature associated with the venting of base metal rich hydrothermal fluids. The calculated relative temperature estimates are in accordance with this interpretation and show a remarkable correlation with the known limits of the Central and East Thalanga orebodies. The recently discovered Orient orebody is also associated with an elevated temperature



GEOCHEMICAL
LEGEND
Colour :
Size :
X : EAST
Y : RL

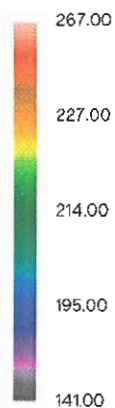


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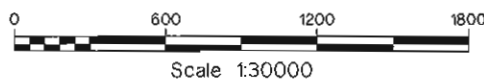
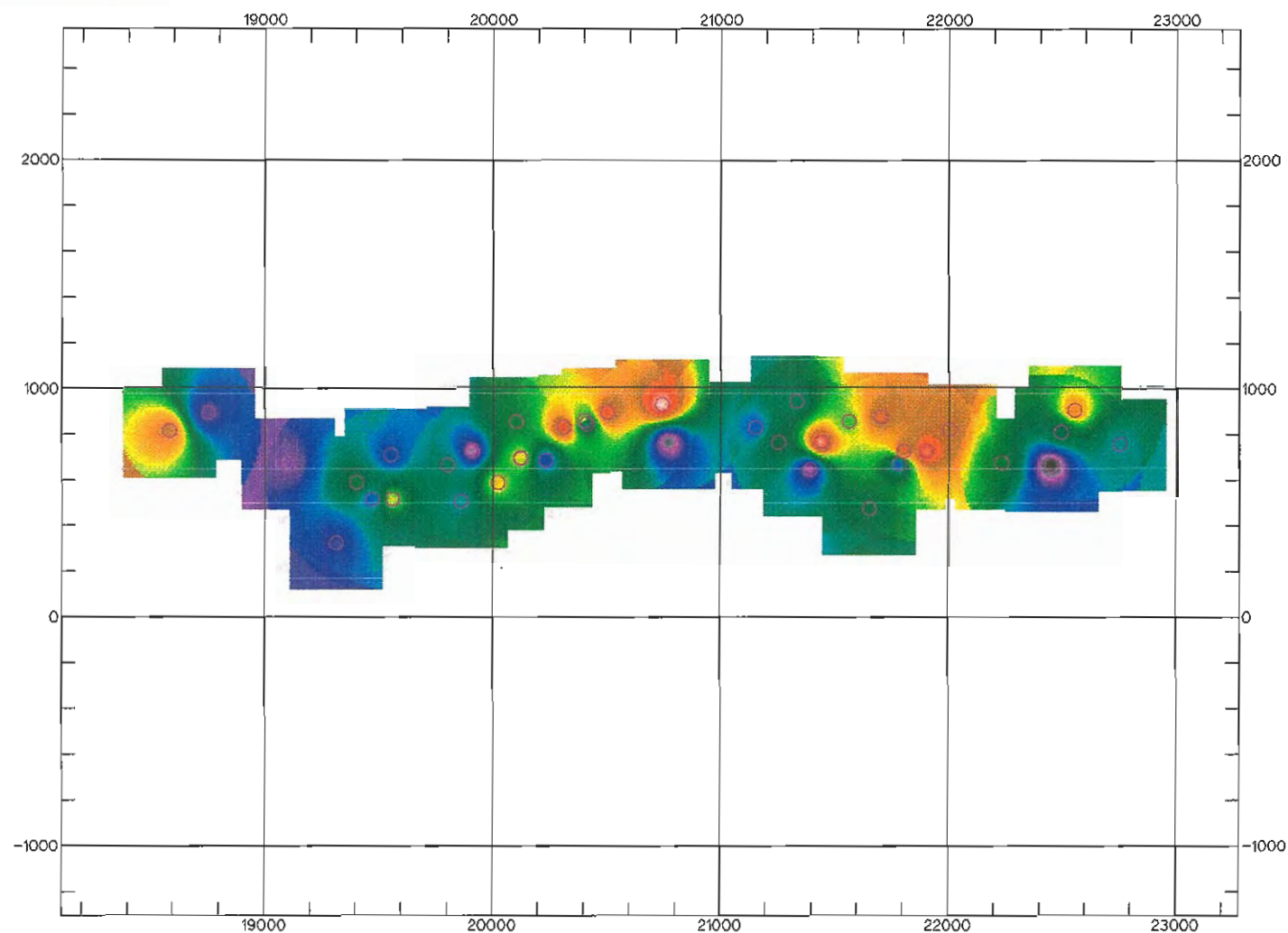
THALANGA - LONG SECTION

Del O18 Whole Rock Data (per mil)
Gridded & Imaged

GEO: CRM	SCALE 1:30000	REPORT: LT THESIS
DRAWN: CRM	DATE: 15-04-1996	PLAN: Fig 28



GEOCHEMICAL
LEGEND
Colour :
Size :
X : EAST
Y : RL



RGC EXPLORATION PTY LTD

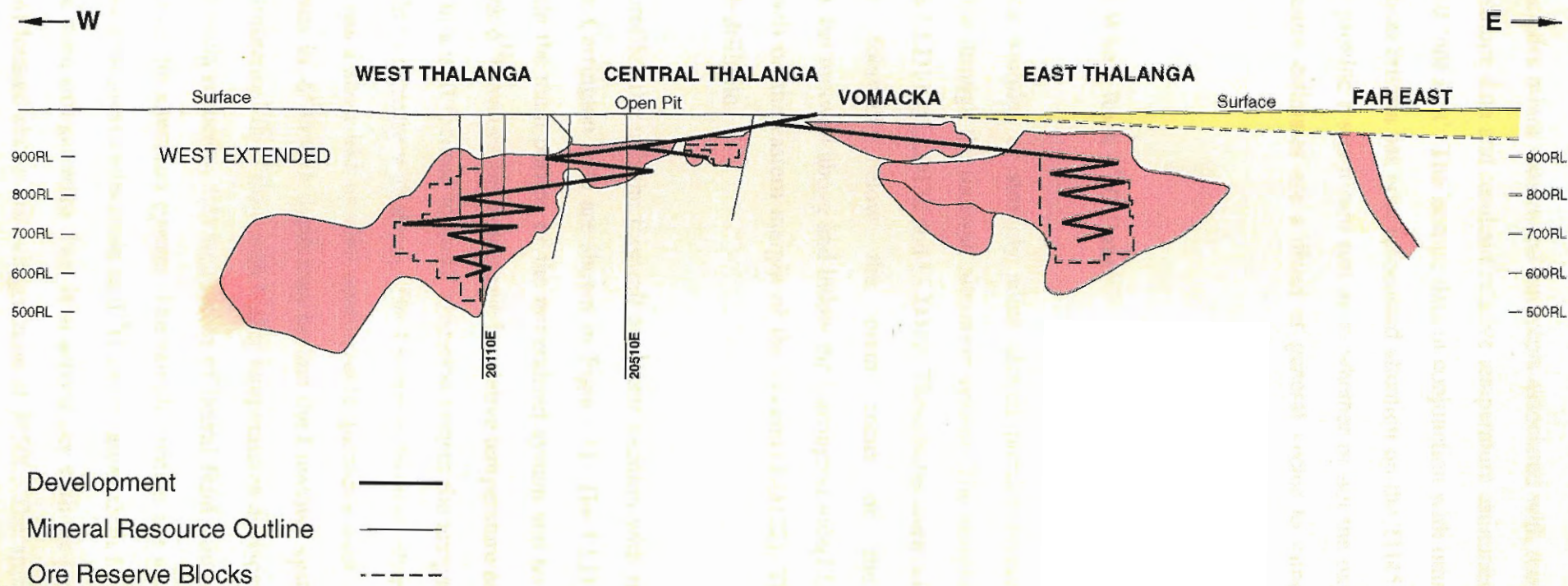
THALANGA - LONG SECTION

Relative Temp C

Calc from Del O18 Data

GEO: CRM	SCALE 1:30000	REPORT: LT THESIS
DRAWN: CRM	DATE: 15-04-1996	PLAN: Fig 29

THALANGA MINE **Vertical Long Projection**



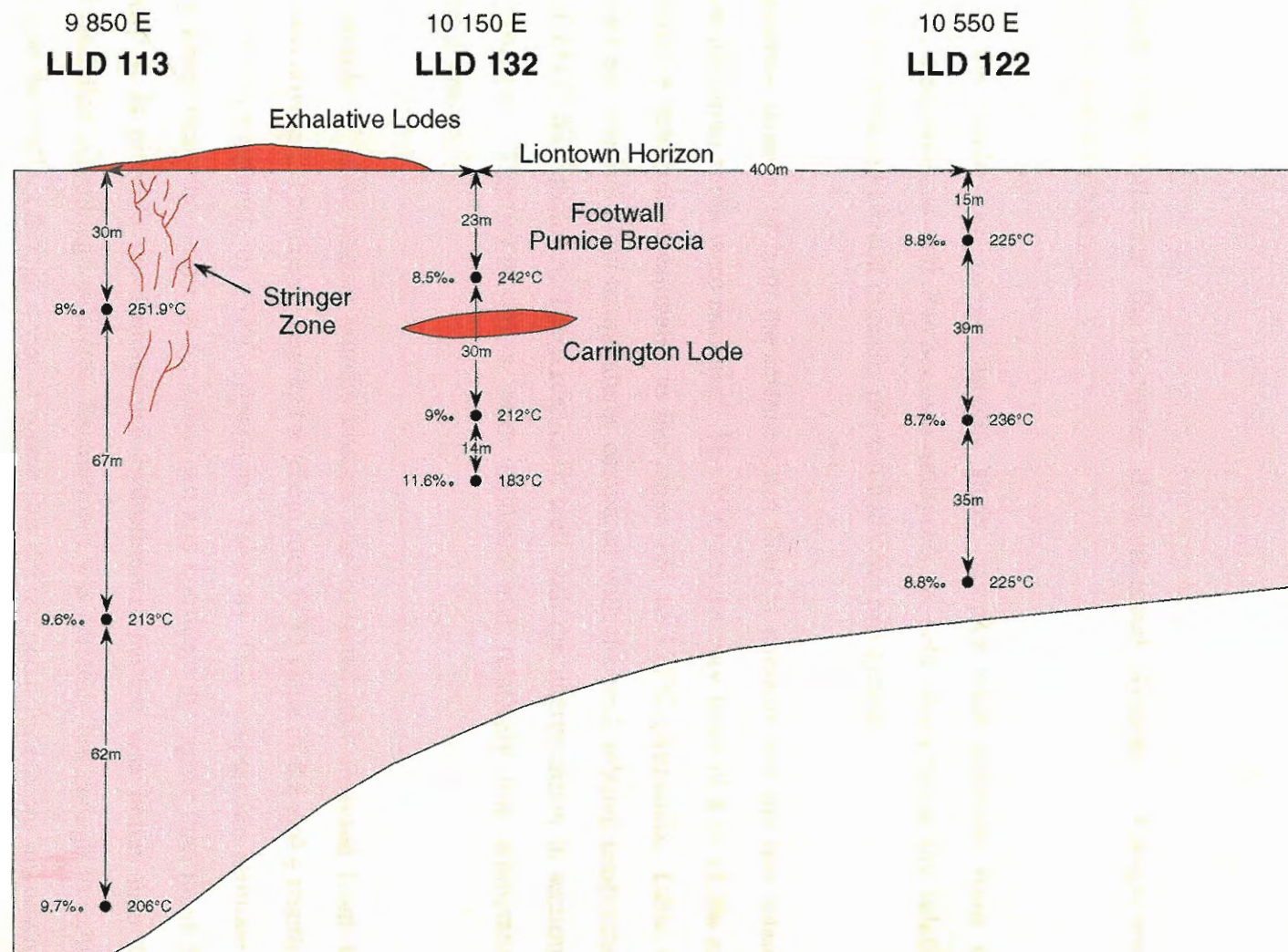
estimate at 22550E. The elevated temperature estimate located on section 18590E is known as the TH45 area and includes minor base metal intercepts associated with moderate-strong alteration. The oxygen isotope data and resultant relative temperature estimates suggest this area may be an additional 'hot spot'. The isotope data in conjunction with other supporting geological and geochemical criteria has now refocussed attention on the TH45 area. Future drilling in this area will provide a significant test as to whether or not the oxygen isotope derived relative temperature estimates are a direct or general vector to mineralisation at Thalanga.

8.2 A Depth Perspective of Whole Rock $\delta^{18}\text{O}$ Data

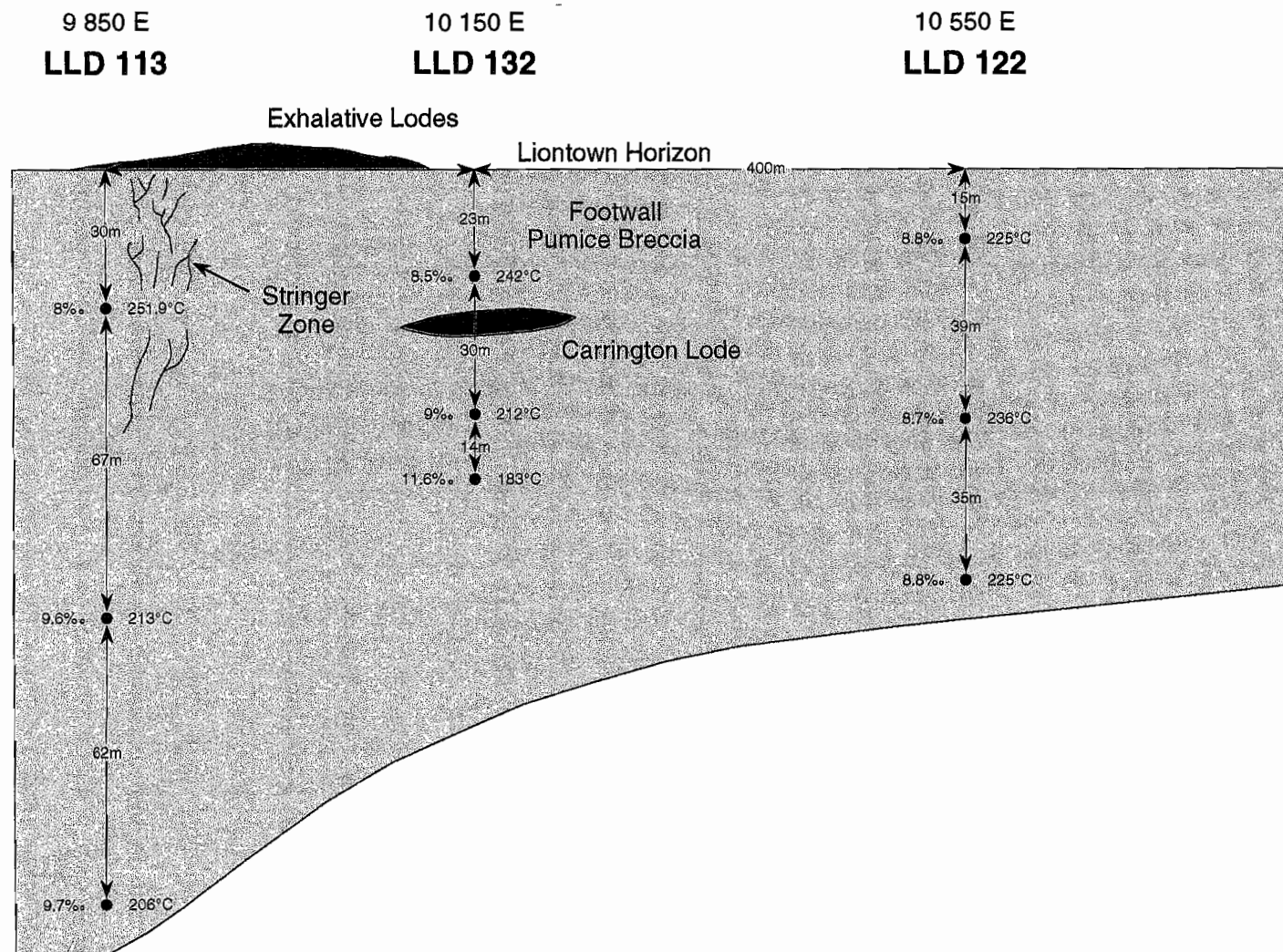
At Liontown whole-rock samples of strongly silica altered pumice breccia were also collected at various depths through the footwall alteration system. The samples were taken from diamond core holes LLD113, LLD132 and LLD122. These holes were selected to gain profiles through the footwall below the main focus of the exhalative mineralisation (LLD113), the footwall above and below the Carrington lode (LLD132) and a profile through the footwall on the eastern margin of the system (LLD122). Three samples were collected from each drillhole.

Temperature and $\delta^{18}\text{O}$ profiles through the footwall and their location with respect to the exhalative lodes and the Carrington lode are shown in Figure 31. The LLD113 and 132 profiles are located within the main portion of the mineralised system and both exhibit an increase in the whole-rock $\delta^{18}\text{O}$ values and a decrease in relative temperature estimates with depth into the footwall. In a well focused footwall alteration system the temperature would conventionally be thought to increase with depth. The Liontown footwall alteration system is not well focused and has a sheet like or semi conformable geometry over ~7 kms. One explanation for the increase in $\delta^{18}\text{O}$ with depth may be that the Liontown system has been dominated by lateral hydrothermal fluid flow with higher temperatures developed in the top 20-40m of the pumice breccia sequence, this suggestion of lateral fluid flow also fits well with the observed length of the alteration system. The samples within the top 40m of the pumice breccia also show a progressive increase in $\delta^{18}\text{O}$ values away from LLD113 which is situated adjacent to the main stringer zone. This is in accordance with the proposal of the main vent zone (hot spot) located above the stringer zone at 9950E. The apparent lack of

WHOLE ROCK $\delta^{18}\text{O}$ VARIATION THROUGH THE LIONTOWN FOOTWALL. $\delta^{18}\text{O}\text{‰}$, TEMP $^{\circ}\text{C}$.



WHOLE ROCK $\delta^{18}O$ VARIATION THROUGH THE LIONTOWN FOOTWALL. $\delta^{18}O\text{‰}$, TEMP $^{\circ}C$.



temperature variability on section 10550E may due to the presence of the weak to moderately developed eastern stringer zone. The preceding interpretations are at best tenuous and to analyse such a small data set further would be misleading. Nevertheless an interesting trend in the available data has been observed and follow up infill sampling and analysis is required.

8.3 Whole Rock $\delta^{18}\text{O}$ Data for the Satellite Hydrothermal Systems - Cougartown, Leopardtown, and Panthertown.

As part of the whole rock oxygen isotope study, samples were collected from the Cougartown, Leopardtown and Panthertown prospects to help characterise the relative temperature regimes and general intensity of each hydrothermal system.

At **Cougartown** samples of both the intense silica flooded domains and the less intense silica-albite alteration zones were analysed. The $\delta^{18}\text{O}$ results vary from 12.8 to 15.3‰ and produce relative temperature estimates in the range 124 to 156°C (Appendix, Table 8). Clearly these are relatively low temperatures compared with the peak relative temperature estimate of 252°C for Liontown. These results fit well with the interpretation in section 6 that Cougartown - Tigertown was a weak oxidised and relatively low temperature hydrothermal system.

A single sample of silica altered pumice breccia was collected and analysed from the **Panthertown** prospect. The sample returned a whole rock $\delta^{18}\text{O}$ value of 8.8 and a resultant relative temperature estimate of 232°C (Appendix, Table 8). This temperature estimate is marginally lower than the estimates for Liontown and considerably higher than those for Cougartown. It is possible the Panthertown hydrothermal system was hotter than the preserved alteration assemblage indicates. Panthertown was certainly hot enough to exhale sulphides onto the seafloor though it would appear this did not occur for reasons unknown.

Three samples were collected from the **Leopardtown** alteration system. The samples were taken from diamond drillhole LPD001 at various depths through the alteration system. The whole rock results range from 6.7 to 10.8 per mil (Appendix, Table 8). The 6.7 per mil

value comes from the most intensely altered part of the system located next to semi massive pyrite stringers with a weak Cu-Au association. The 6.7 per mil value translates into a relative temperature of 256°C and the 10.8 per mil value produces a relative temperature of 195°C. A hydrothermal fluid value of 0 per mil (Cambo-Ordovician seawater) has been used in the temperature calculation. The use of this fluid value may be inappropriate as Leopardtown has not been shown to be unequivocally VHMS related.

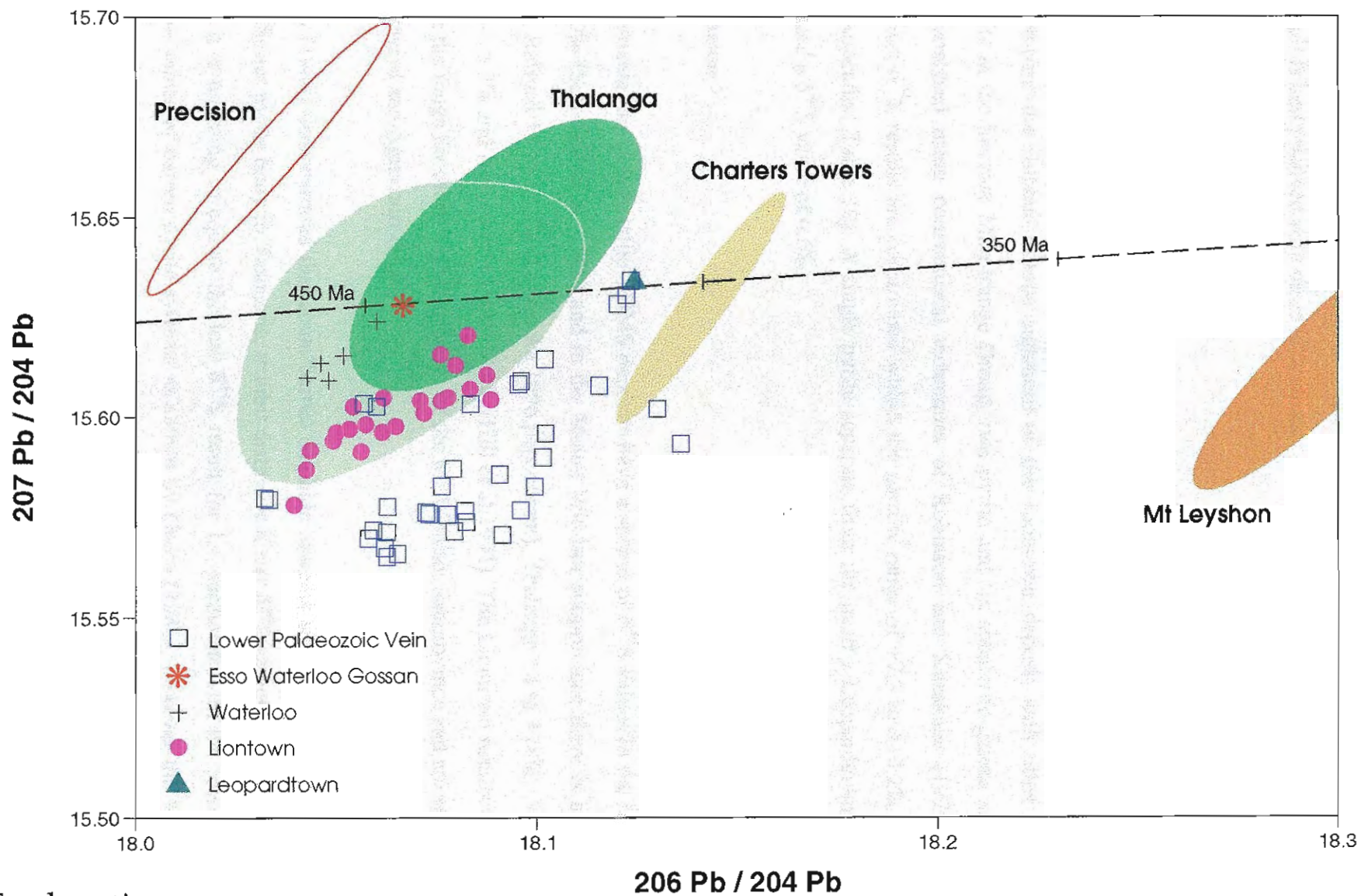
8.4 Lead Isotope Geochemistry

The lead isotope data for Liontown, shown in Figure 32, are sourced from the CSIRO lead isotope database (Appendix, Table 9). The original samples were collected by BHP in 1983 as part of an Australia wide study and the lead ratios determined by CSIRO in Sydney. All samples are galena-sphalerite mineralisation taken from diamond holes drilled by Esso in 1983.

The separation between the Liontown and Thalanga data sets is distinct and shows that different source rocks have been leached in each system. Thalanga, being a relatively strong system and located lower down in the stratigraphy, may have leached lead from deeper basement whereas the stratigraphically higher Liontown system may have only accessed lead from the Trooper Creek Formation. Strontium isotope studies in Western Tasmania suggest that the circulating hydrothermal fluids responsible for the VHMS mineralisation may also have come in contact with deep pre-Cambrian basement (Whitford and Korsch, 1992). Alternatively Thalanga lead has been sourced from the Mt Windsor rhyolite (which may or may not have a different signature to the Trooper Creek volcanics). Distinct magmatic sources cannot be ruled out.

Lead isotope studies have been shown by Gulson et al (1987) to be an effective method of finger printing VHMS deposits and more generally in discriminating between VHMS mineralisation and other unrelated styles mineralisation. To this effect a sample of massive pyrite stringer material from the Leopardtown system was despatched to Sirotope (Sydney) for lead isotope ratio determination. The sample selected contained 245 ppm lead, the highest lead content of all available drill core samples. The results illustrated in Figure 32 are ambiguous, which is often the case with low lead samples (Gulson et al, 1987). Because

Pb ISOTOPE PLOT



of the low level of lead in the Leopardtown sample, the addition of radiogenic lead since the time of the mineralisation event could have shifted the isotopic ratios. The ratios presented here should therefore be regarded as maximum values. The ambiguity of the Leopardtown Pb result is best resolved with other techniques.

8.5 Sulphur Isotope Geochemistry

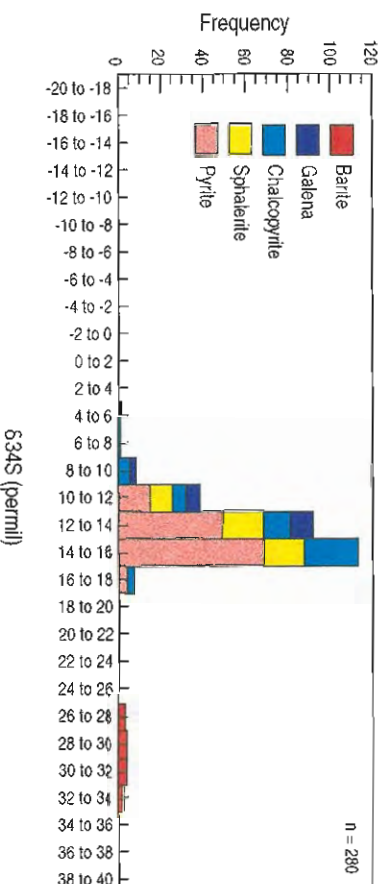
To compare the sulphur isotope signature of the Liontown deposit with other VHMS deposits in the Seventy Mile Range Group, two pyrite and six sphalerite-galena separates were analysed using conventional techniques of Robinson and Kusakabe (1975). The Liontown $\delta^{34}\text{S}$ results are constrained within the narrow range of +7.3 to +10.2‰ (Figure 32a, Appendix, Table 10). A single pyrite separate from the nearby Leopardtown system produced a $\delta^{34}\text{S}$ value of 0.6‰.

Discussion

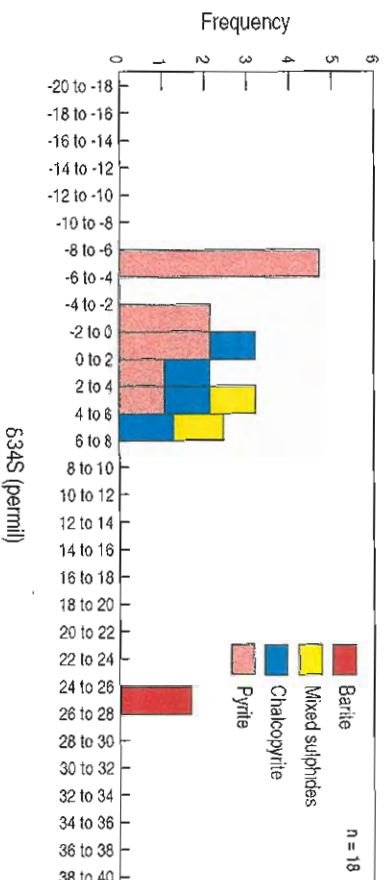
In Tasmania the polymetallic VHMS deposits have a spread of $\delta^{34}\text{S}$ values in the range +5 to +20‰ (Solomon et al, 1988) and in the Mount Windsor subprovince there is a similar range; Reward +5 to +8.7‰ (Dronsioka 1996, pers comm), Thalanga +8 to +18‰, Waterloo -6.0 to +6.5‰ and Agincourt +3.9 to +8.9‰ (Hill et al, 1991). The Liontown results fall well within the range for other VHMS deposits of the Mt Windsor subprovince and are similar to the Reward and Agincourt ranges.

Green (1986) demonstrated that some barren sulphide systems such as the Boco prospect and Chester pyrite body in Tasmania, exhibit distinctly lower $\delta^{34}\text{S}$ values in the range -2 to +5‰. It is tempting to equate the low $\delta^{34}\text{S}$ result for Leopardtown with the low sulphur isotope values of barren pyrite systems as shown by Green (1986), however the Waterloo deposit which is situated 2.6km to the northeast of Leopardtown provides pyrite and chalcopyrite sulphur isotope values in the range -6.0 to +5.1‰. Clearly the Leopardtown result is well within this range and could indeed be related to a Waterloo type VHMS system.

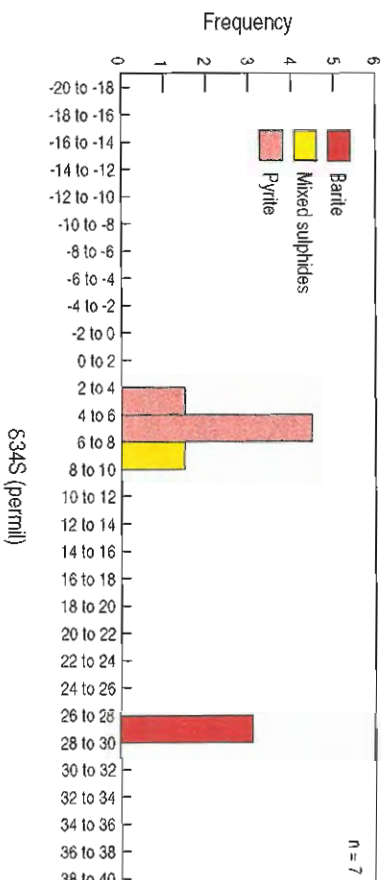
Thalanga



Waterloo



Aginccourt



Liontown

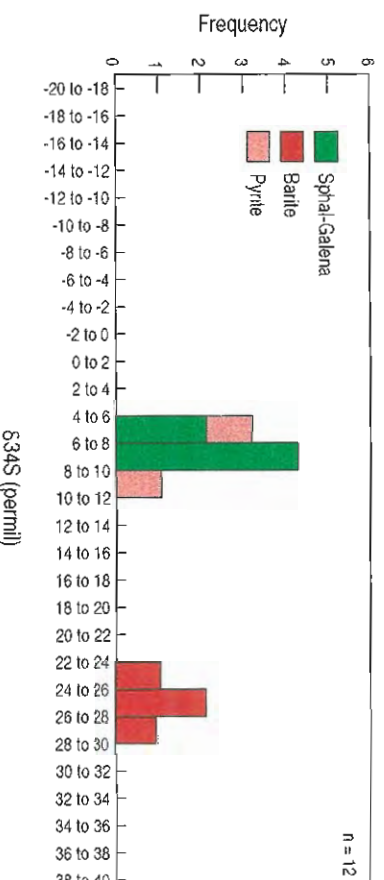


Figure 31a Summary of the $\delta^{34}\text{S}$ values for Thalanga, Waterloo, Aginccourt and Liontown. (Thalanga, Waterloo & Aginccourt data from Hill et al 1991)

Ohmoto and Rye (1979) state that $\delta^{34}\text{S}$ values of +3 to +7‰ characterise high oxidation states, and as the assemblages at Agincourt and Waterloo are oxidised with barite at both deposits and bornite at Waterloo. Hill et al (1991) suggest that high oxidation state explains the low $\delta^{34}\text{S}$ values from the Waterloo system. They also suggest that alternatively, the low $\delta^{34}\text{S}$ values may be the result of a mixed seawater-biogenic source of sulphur. In oxidised and/or low temperature systems, the inorganic reduction of seawater sulphate will be inefficient, and the sulphur isotope ratios in the sulphides will probably reflect the composition of rock sulphur that is being leached from the volcanic pile (presumably this will be around 0 per mil), this process may also contribute to the production of low $\delta^{34}\text{S}$ values.

At Liontown-Tigertown the stratiform ore horizon mineral assemblage is also oxidised with a far greater volume of barite, massive carbonate, rare hematite and ubiquitous low iron sphalerite, this oxidised mineral assemblage indicates oxidising conditions at the site of deposition (local oxidation at the seawater interface) but the transport conditions may not be so oxidised. However the presence of low iron sphalerite in quartz-pyrite stringers developed at least 80m below the footwall-Liontown Horizon boundary suggests that the transport conditions probably were relatively oxidised, at least as oxidised as Waterloo. The Liontown pyrite-base metal sulphide $\delta^{34}\text{S}$ values are in the range 7.3 to 10.2‰. Clearly the higher $\delta^{34}\text{S}$ values for Liontown are at odds with the "oxidised" explanation put forward by Hill et al (1991). It would seem the low $\delta^{34}\text{S}$ values are indeed more likely to be the result of a mixed seawater-rock \pm biogenic sulphur source.

To help characterise the barite associated with VHMS mineralisation in the upper-most stratigraphic levels of the Trooper Creek Formation, samples from Tigertown and Liontown were submitted to Sirotope (Sydney) for $\delta^{34}\text{S}$ determination. The sulphur isotope values for Tigertown are in the range +27.8 to +29.0‰ and at Liontown are in the range +23.6 to +26.3‰. Surface seawater at the time of the formation of the Tigertown and Liontown deposits (Cambro-Ordovician) is assumed to have had a $\delta^{34}\text{S}$ value of near 30 per mil (Claypool et al, 1980). The Tigertown-Liontown $\delta^{34}\text{S}$ values as expected, are consistent with a Cambrian-Ordovician seawater sulphur source, and are comparable with the barite

$\delta^{34}\text{S}$ values from the base of the Trooper Creek formation at Thalanga and Mt Farrenden which vary between +27 and +32‰ (Hill et al, 1991).

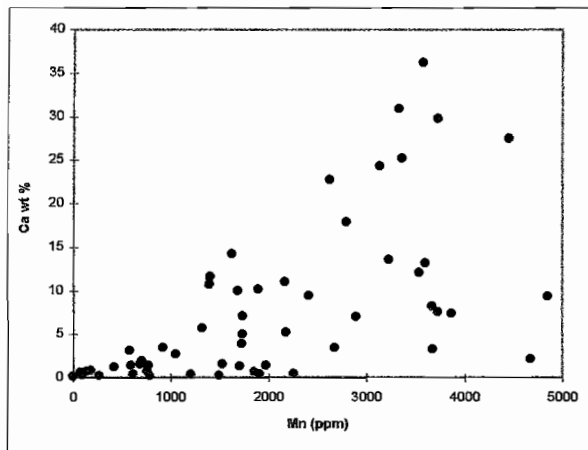
9.0 GEOCHEMISTRY OF THE LIONTOWN HORIZON CARBONATE FACIES

9.1 Trace Element Associations

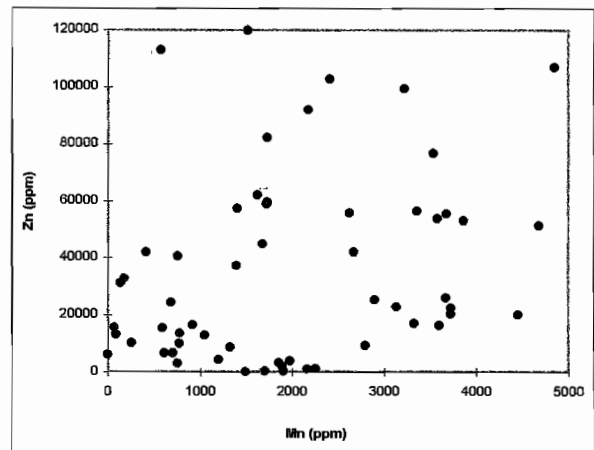
The Liontown Horizon has an abundance of carbonates intimately associated with all three stratiform lodes. The lower lode has a calcite veinlet association, massive carbonate is rare. The central lode has the best development of carbonate (calcite and dolomite) and displays a wide variety of textures including massive recrystallised carbonate, foliated carbonate intermingled with base metal sulphides, carbonate blebs and spheroids and later cross cutting veinlets of calcite. The upper lode carbonates are typically developed in close association with barite and exhibit barite-silica-carbonate-sphalerite banding and rare bladed textures possibly after the replacement of crystalline barite.

The massive blebby and recrystallised carbonates of the central lode are the most laterally continuous and often persist up to 100m beyond the limits of the base metal mineralisation. A line of investigation followed early in the study sought to determine whether the base metal sulphide-carbonate relationship is due to the sulphides having replaced carbonate or due to a co-precipitation association. The recrystallisation of much of the carbonate and indeed some of sulphides negates any meaningful interpretation of the existing textures. Despite the complication of recrystallisation there is consistent textural evidence to suggest the carbonate has at least replaced large volumes of sericitic siltstone. Massive carbonate is regularly observed as having replaced siltstone leaving apparently 'broken up' islands of siltstone fragments with embayed and 'corroded' margins.

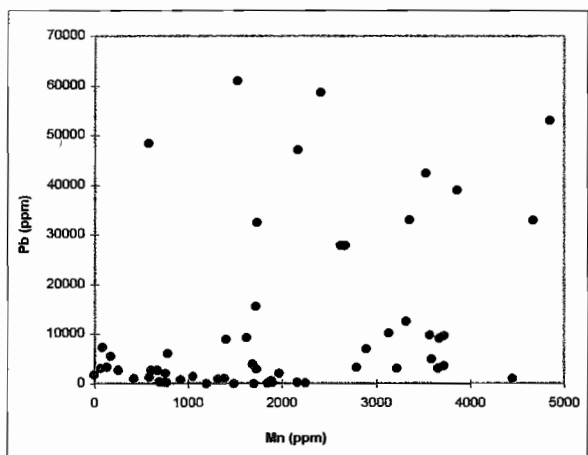
The Liontown carbonates are dominated by calcite Ca 38-40 wt% though also include minor dolomite Ca 22 wt%, Mg 11 wt% (Appendix, Table 12). Prior to this study it was thought the Liontown carbonates had a significant manganese component as is the case with the carbonates from the Rosebery and South Hercules deposits in Tasmania. Khin Zaw and Large (1992) report the carbonates from South Hercules are kutnohorite and rhodocrosite



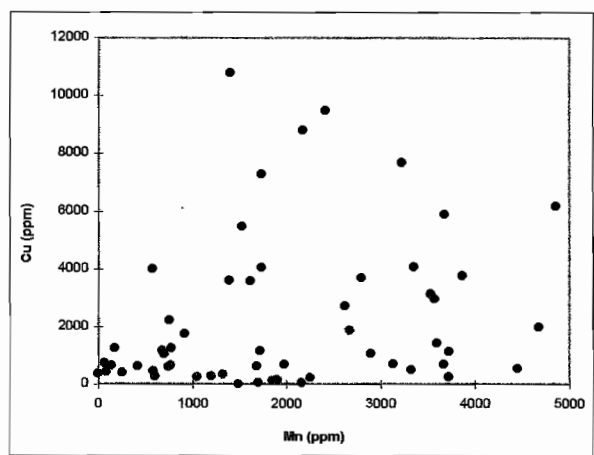
Ca Vs Mn $r = 0.62$



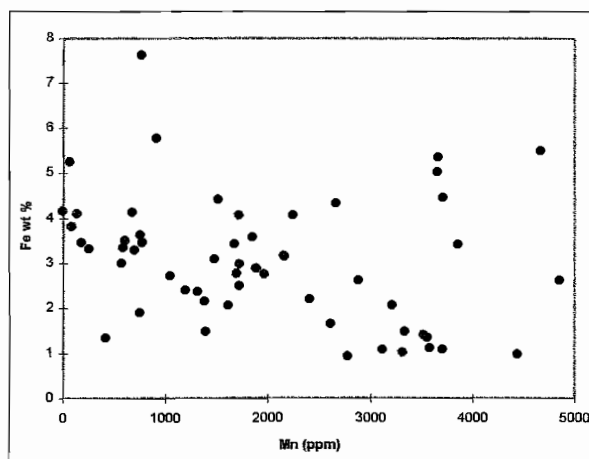
Zn Vs Mn $r = 0.28$



Pb Vs Mn $r = 0.35$



Cu Vs Mn $r = 0.25$



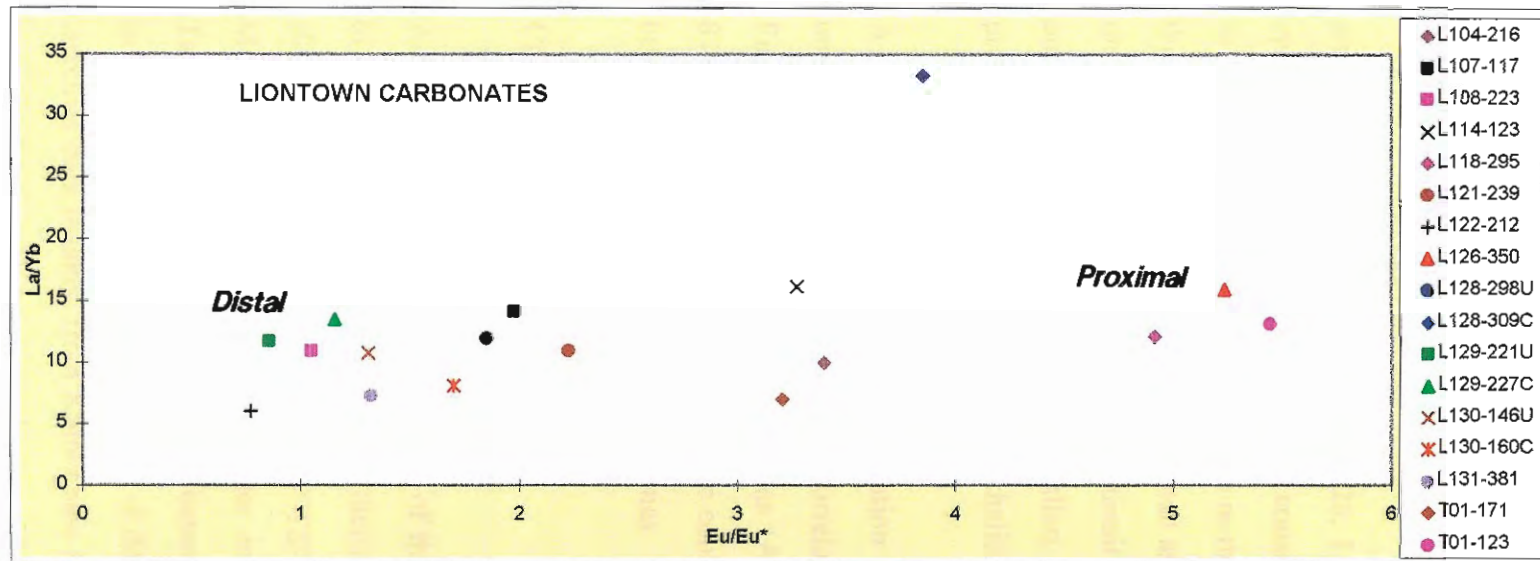
Fe Vs Mn $r = -0.28$

Figure 33: Lontown Exhalative Carbonates - Base Metal Lodes - Scattergrams.

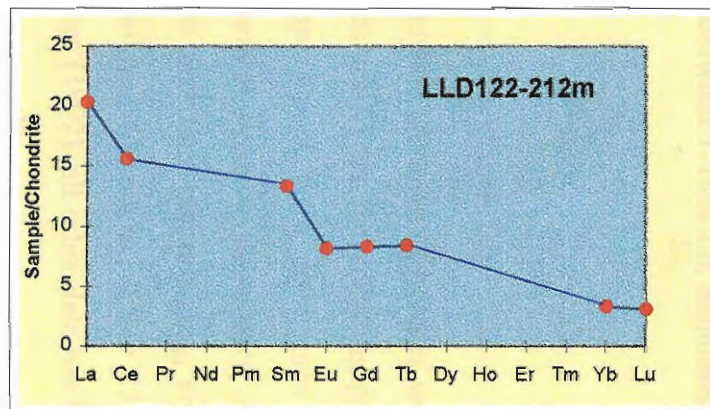
with Mn levels of between 17.5 - 38.2 wt%. The Liontown manganese bearing phase is calcite with Mn levels of between 0-2 wt%. Carbonate Ca, Mn, Mg, Fe, Zn, Zr, Ba trace element data is sourced from 23 Cameca Microprobe analyses undertaken during this study at the Central Science Laboratory, University Tasmania. Figure 33 shows a series of scattergrams depicting the variation of Mn with Cu, Pb, Zn, Fe and Ca. This data is taken from standard AAS and ICP assays of the base metal-carbonate lodes and shows a moderate-strong correlation ($r = 0.62$) between Ca and Mn. Cu, Pb, Fe, and Zn do not display significant correlations with Mn which further suggests Mn is exclusive to the calcite phase. The Mn content of carbonate \pm base metal lodes is erratic and there is no consistent lateral variation. The development of carbonate seldom extends more than 100m from base metal sulphide mineralisation, this close spatial relationship between the carbonates and base metal sulphides is also noted at Tigertown.

9.2 Carbonate Rare Earth Element Patterns

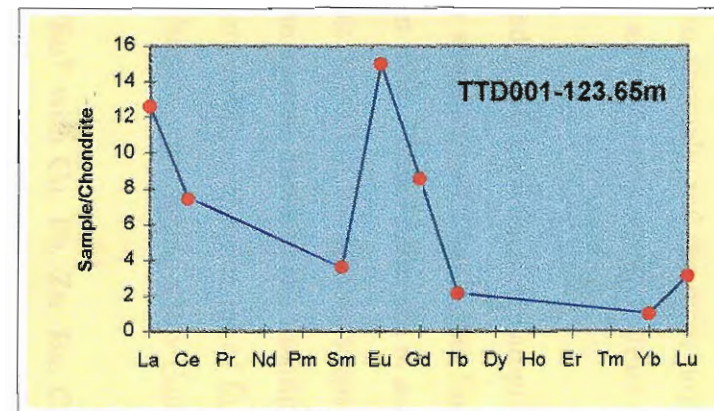
There have been numerous studies that document strong evidence for the mobility of REE's during hydrothermal alteration (Schade et al, 1989). REE mobility is enhanced by the presence of HF-bearing fluids which also increases the potential for mobility of Ti, Zr, and P (Stolz, 1991). Studies show the trivalent REE are lost during sericitic alteration, LREE are lost during chloritisation and argillic alteration, and all of the REE are mobilised during tourmalinisation (Alderton et al, 1989). Europium is routinely documented as depleted in the feldspar destructive sericite alteration zones footwall to many VHMS systems (Schade et al, 1989). The Eu^{2+} is liberated from feldspars by a corrosive acid bearing hydrothermal fluid and mobilised as Eu^{2+} to higher levels in the system. In the case of an exhalative system the Eu^{2+} will often be expelled with the exhalite fluid and with cooling and oxidation will become fixed in the Eu^{3+} state within the exhalite horizon. As a result the plotted position of Eu lies above the general trend defined by the other elements on a REE spidergram and is referred to as a europium anomaly. In VHMS systems the base metal sulphide, carbonate, baritic and siliceous exhalites may each have a europium anomaly. If the plotted position lies above the general trend normalised to chondrite then the anomaly is described as positive and if below it is referred to as negative. Footwall alteration zones often show negative anomalies. Unaltered felsic volcanics may also have primary negative Eu anomalies.



[a]



[b]



[c]

Figure 34: Liontown exhalative carbonates - REE abundances and trends in binary plots.

The REE chemistry of the Liontown carbonates has been incorporated into this study to investigate the potential for vectoring to base metal sulphide mineralisation. I have endeavoured to investigate the REE concentrations of only the carbonate exhalite phases. A light 2M HCl acid leach of the crushed samples was employed to digest only the carbonate phases, leaving the silicates intact (S Finlayson, A.L.S. pers com). The REE analyses were completed by ICP-MS (A.L.S., Brisbane). All samples were collected from diamond core and sample selection was designed to provide widespread lateral coverage of the carbonates across the system. In all instances the sample collected consisted of massive and visually pure carbonate. The calcite/dolomite proportion of each sample was not determined though microprobe analyses of similar material (section 9.1) indicate that calcite is the dominant carbonate phase at Liontown and Tigertown.

Results and interpretation:

All results were returned as REE concentrations in ppm, these values were subsequently normalised using the chondrite values of Boynton, 1984 (Appendix, Table 11). Many of the samples, when plotted as spidergrams, show well developed positive europium anomalies. Europium anomalies may be quantified by comparing the measured concentration of Eu with an expected concentration obtained by interpolating between the adjacent normalised REE values (Eu*). A common measure of the europium anomaly is Eu/Eu* and a value of greater than 1.0 indicates a positive anomaly (Rollinson, 1993). To calculate Eu/Eu* this study has used the following formula recommended by McLennan, (1985).

$$\text{Eu/Eu}^* = \text{Eu}_n / \sqrt{(\text{Sm}_n \times \text{Gd}_n)}$$

Figure 34 shows the variation of Eu/Eu* versus La/Yb and also includes two REE spidergrams depicting a weakly negative Eu anomaly for distal sample LLD122-212m and a strongly positive anomaly from Tigertown sample TTD001-123.65m. The La/Yb vs Eu/Eu* plot has been previously used in the study of VHMS exhalite horizons to show proximal to distal trends with respect to the hydrothermal vent site (J.Waters,CSIRO pers com). At Liontown it is argued that the main site of hydrothermal discharge is centred at 10,060E and samples are interpreted as proximal or distal based on their distance from this site. Distal samples at Liontown tend to have a low Eu/Eu* ratio as indicated in Figure 34. This

relationship does not always hold with distal samples L126-350 and L128-309 showing high Eu/Eu^* ratios. One of the limiting factors in this study has been the lack of exhalative metal sulphide. In summary, the sampling did not extend into "background" areas. Despite this, there is an erratic proximal to distal trend, with the most distal samples giving a slightly negative Eu anomaly and the most proximal samples (L118-295, T01-123) possessing strong positive anomalies exceeding $\text{Eu}/\text{Eu}^* = 4$.

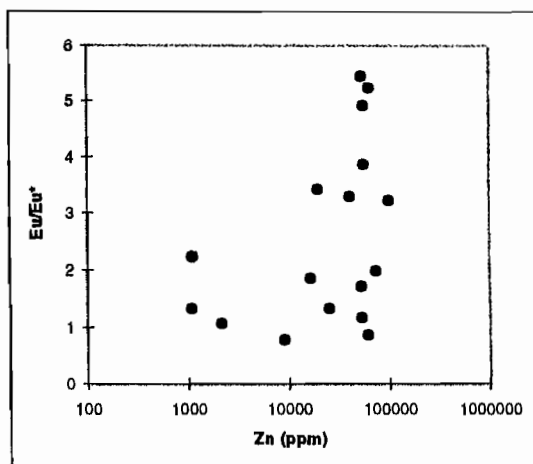
At Liontown the sample series L128, L129 and L130 each include samples of both the upper and central lodes. The results consistently show a trend from higher Eu/Eu^* numbers in the central lode to lower numbers in the upper lode. These results are in accordance with the upper baritic lode being interpreted as having formed in the waning stages of the life of the hydrothermal system. As the intensity of the system declined the mobilisation of Eu^{2+} out of the footwall may also have fallen, therefore reducing the amount of Eu available for precipitation within the carbonate exhalite and ultimately producing a low Eu/Eu^* ratio.

A brief investigation of the covariation of Eu/Eu^* with Cu, Pb, Zn, Ba, Ca and Fe was unable to identify any significant correlations with $r > 0.5$. These results are presented in Figure 35 as a series of scattergrams (Appendix, Table 11). The Zn vs Eu/Eu^* indicates 83% of the samples have a high zinc content of between 1-10% Zn, emphasising the strong bias of the data set to mineralised zones.

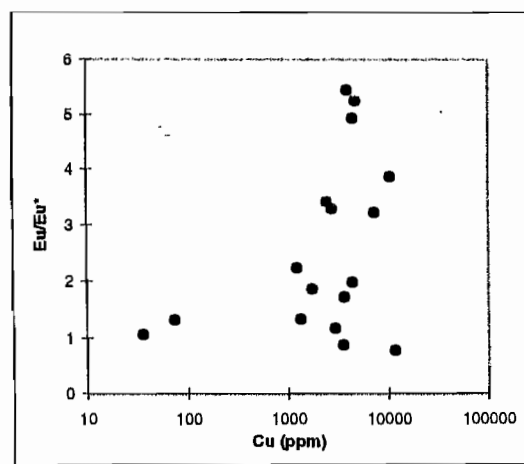
9.3 Carbon and Oxygen Isotopes

A carbon and oxygen isotope study of the Liontown-Tigertown carbonates was undertaken to constrain the source of the hydrothermal fluids and to test the vectoring potential of the stable isotopes. The carbon and oxygen isotope values were determined using a VG Micromass 602D mass spectrometer in the central Science Laboratory, University of Tasmania. The $\delta^{18}\text{O}$ values range between 8.28 and 13.9 per mil_(SMOW) and the carbon isotope values vary from 0.35 to -8.04 per mil_(PDB) (Appendix, Table 13). The South Hercules data is taken from Khin-Zhaw and Large (1992), all other data has been acquired from the RGC exploration database.

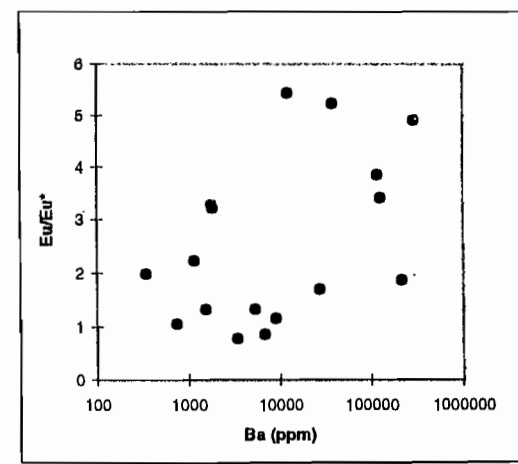
A plot of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values showing samples from the central and upper lodes and three samples from Tigertown is provided in Figure 36a. There are no obvious correlations in the



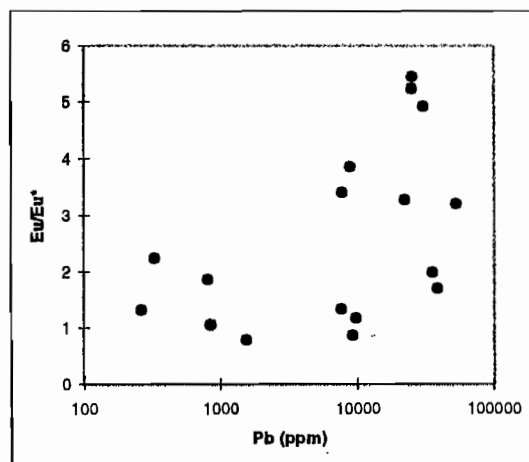
$r = 0.42$



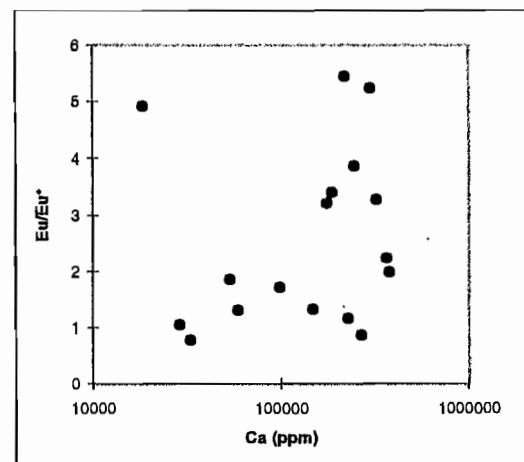
$r = 0.21$



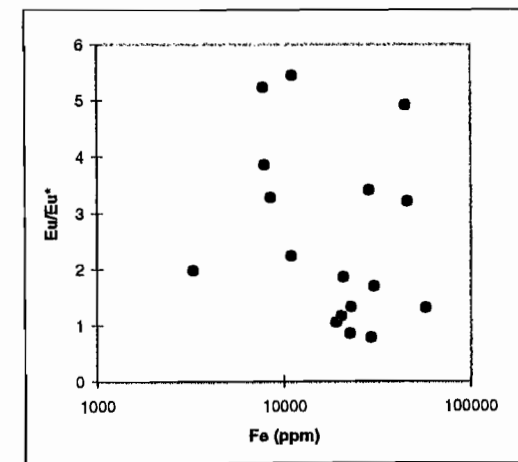
$r = 0.40$



$r = 0.45$



$r = 0.23$



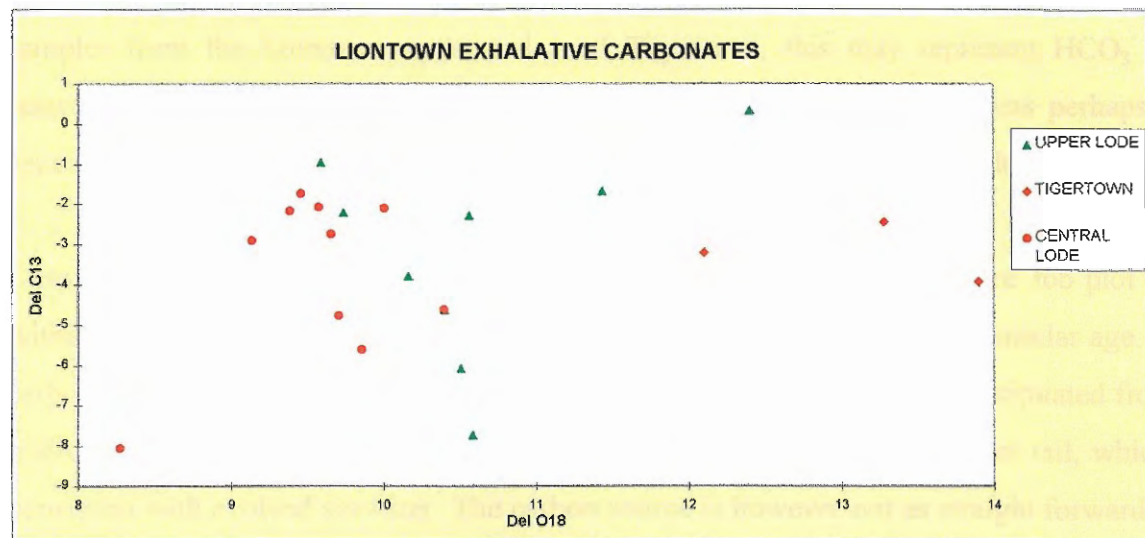
$r = -0.17$

Figure 35: Lontown Exhalative Carbonates Eu/Eu* Scattergrams.

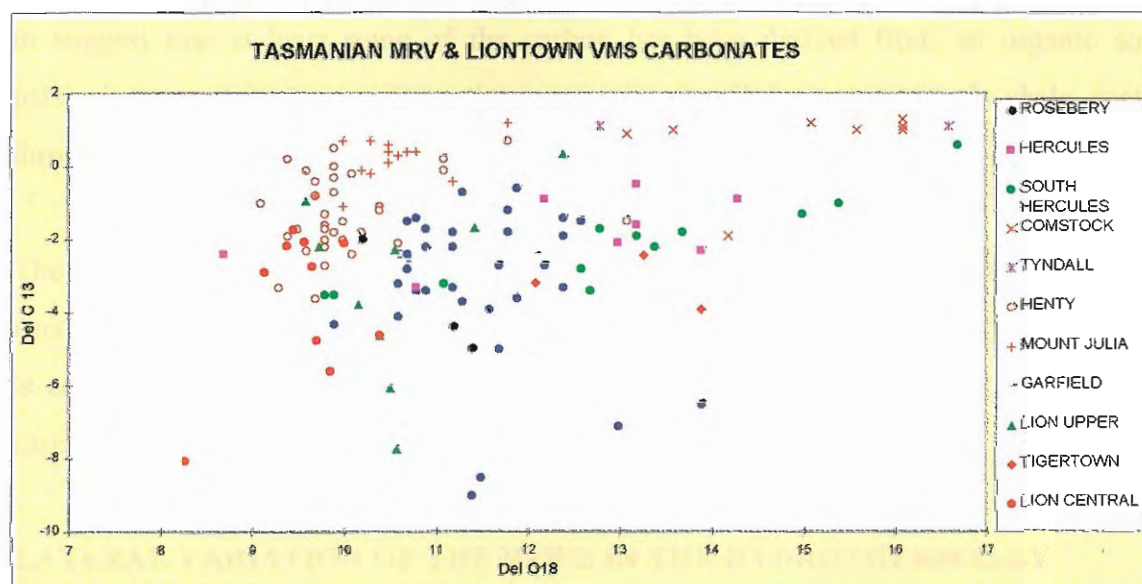
data set (correlation coefficient = 0.22) apart from a weakly developed negative trend between $\delta^{18}\text{O} = 9$ and $\delta^{18}\text{O} = 11$, this possibly reflects a water/rock interaction line. This trend includes data from both the upper and central lodes. If the central and upper lode samples are viewed together then only 16% of the samples show a significant departure from this trend. Negative isotopic trends have been shown by Matsuhisa et al (1985) and Simmons and Christenson (1994) to be related to calcite crystallisation from a fluid dominated by the HCO_3^- aqueous species (common in seawater) as opposed to the 'more common' H_2CO_3 species. Matsuhisa et al, (1985) also consider HCO_3^- to be dominant at lower temperatures.

The Tigertown samples in Figure 36a plot to the right hand side of the Liontown population due to their elevated $\delta^{18}\text{O}$ values. The Tigertown system has been consistently interpreted throughout this study as a lower temperature hydrothermal system and these higher $\delta^{18}\text{O}$ values are in accordance with this interpretation. Figure 36b shows $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ results taken from numerous studies of VHMS related carbonates in the Mount Read Volcanics, Tasmania, and the Liontown-Tigertown results of this study. The South Hercules data set was interpreted by Khin Zaw and Large (1992) to represent a cooling trend where carbonates were precipitated over a temperature range of 150° to 250°C from a hydrothermal fluid with an isotopic composition of 2 to 4 per mil. In Figure 36b a similar cooling trend is also observed in the Henty-Mt Julia-Comstock data series, all are interpreted to belong to the one carbonate exhalite horizon (Halley, 1996 pers comm.). In Figure 36b lower temperature samples from the South Hercules data set taken from Khin Zaw and Large (1992), have the higher $\delta^{18}\text{O}$ values, and higher temperature samples have lower $\delta^{18}\text{O}$ values. Khin Zaw and Large (1992) demonstrated that the South Hercules carbonates were precipitated from a fluid where the H_2CO_3 species was dominant.

If the Liontown carbonates were also precipitated from a fluid dominated by H_2CO_3 and with a fluid composition similar to that of the South Hercules system then the Liontown carbonates could be interpreted as having formed at the higher end of the temperature spectrum for Cambro-Ordovician VHMS carbonates. If however the Liontown carbonates were precipitated by a HCO_3^- dominated fluid with an isotopic fluid composition quite different to the 2-4 per mil estimated for the South Hercules system then the Liontown carbonates could be just as easily interpreted as having formed at the lower end of the temperature spectrum. Given that the Liontown hydrothermal system like most other VHMS



[a]



[b]

Figure 36: VMS related carbonates from Liontown and the Mt Read Volcanics (Western Tasmania) - Del O18 and Del C13 plots.

systems was most likely dominated by acidic fluids then it is perhaps unlikely that HCO_3^- was the dominant aqueous species as HCO_3^- is only stable at $\text{pH} > 6.3$ in the temperature range 0-300°C (Helgeson, 1969). Nevertheless in figure 36a there is a flat trend comprising samples from the Liontown upper lode and Tigertown, this may represent HCO_3^- and seawater dominated, low temperature (<100°C) hydrothermal fluids whereas perhaps the central lode carbonates were precipitated from a higher temperature H_2CO_3 dominated fluid.

Despite the above complications, the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data as shown in Figure 36b plot well within the carbonate VHMS field for other Australian VHMS systems of a similar age. The carbonates from the bulk of these deposits have been interpreted to have precipitated from a hydrothermal fluid with an oxygen isotope composition of around 0 to 4 per mil, which is consistent with evolved seawater. The carbon source is however not as straight forward and may include minor input from organic carbon. In Figure 36b Liontown - Tigertown and Rosebery each have a small number of samples with relatively light $\delta^{13}\text{C}$ values in the range -6 to -9‰. Given that both Rosebery and Liontown are immediately overlain by carbonaceous black shales and that the circulating hydrothermal fluids may have come in contact with other carbonaceous units deep in the footwall region then it is not unreasonable to suggest that at least some of the carbon has been derived from an organic source, particularly at Liontown where there are also small lenses of black shale scattered throughout the Liontown Horizon.

The vectoring potential of the carbon and oxygen isotope data at Liontown appears to be encouraging. From the current data set the weaker and lower temperature Tigertown system is easily discriminated from Liontown using the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of the associated carbonates.

10.0 LATERAL VARIATION OF THE REE'S IN THE HYDROTHERMALLY ALTERED SILTSTONES OF THE "TIME EQUIVALENT KEY HORIZON"

Recent studies of the seafloor sediments surrounding the modern day Pacmanus VHMS field in the Eastern Manus Basin have shown that the Eu/Eu^* ratio is particularly useful in discriminating proximal vs distal locations with respect to the main hydrothermal vent areas (J. Waters, 1996. pers comm). At Liontown the hydrothermally altered sericitic-pyritic siltstones hosting the stratiform carbonate-barite-base metal sulphides lodes are interpreted

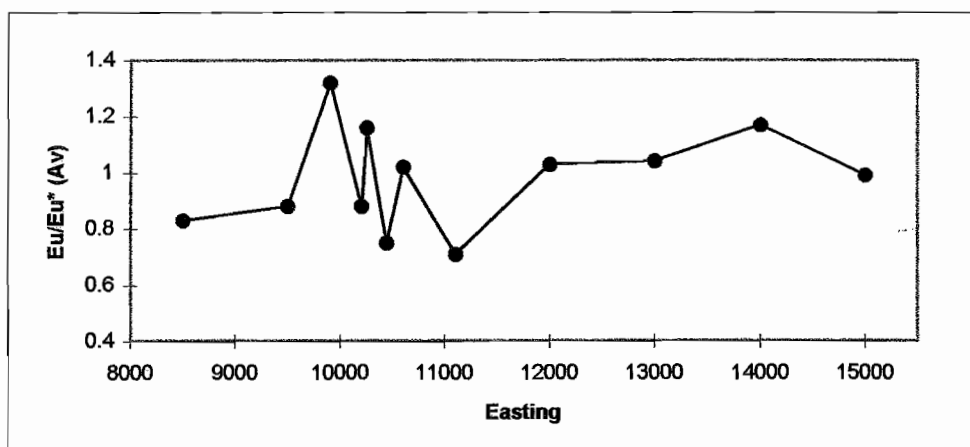
to have mixed with and been altered by the exhalative fluids venting onto the seafloor. This being the case it was thought the 'Liontown Horizon' siltstones may also have europium anomalies with similar exploration potential as that seen at Pacmanus.

To investigate the lateral variation of the REE's in the Liontown Horizon a series of siltstone samples were collected from RC and diamond drillholes over a strike length of 6.5 kms. Where possible the samples were taken from 10-30 metres above the pumice breccia-siltstone interface, though due to sample availability one sample comes from 82 metres above the contact. The REE analyses were undertaken by ICP-MS through ALS (Brisbane). The ICP-MS method was deliberately selected over neutron activation for two reasons: (i) it provides the required low levels of detection and (ii) the sericitic siltstones may contain detrital zircons carrying a REE signature unrelated to that of the exhalative hydrothermal fluid. The ICP-MS with HF digest in effect leaves the zircons intact whereas neutron activation would provide a total REE analysis including the REE locked within the zircon, thus distorting the hydrothermal signature.

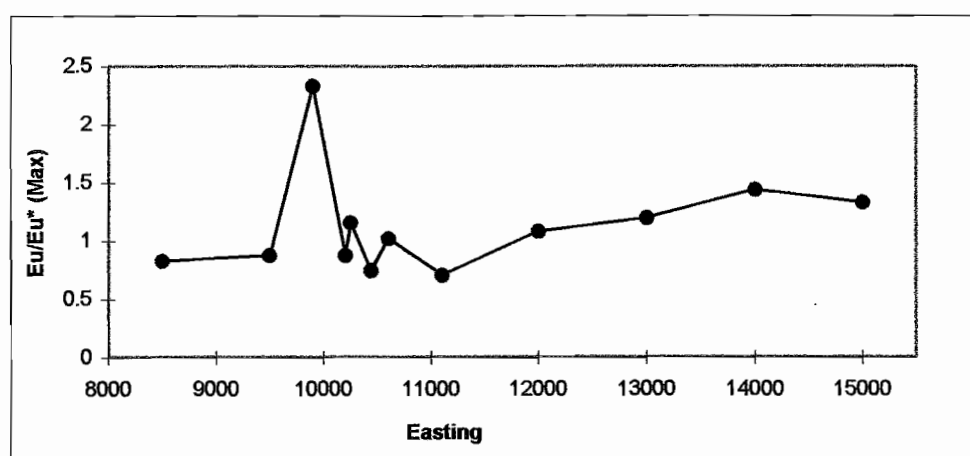
Results and Interpretation

The Eu/Eu* ratio for the entire data set ranges between 0.70 and 2.33 (Appendix, Table 11). The maximum value comes from a series of samples collected from the centre of the Liontown deposit to provide a vertical profile through the Liontown Horizon. The profile on line 9900E (Hole LLD130) has a Eu/Eu* range of 0.88 to 2.33. There is also a weak correlation ($r = 0.65$) between Eu/Eu* and Zn (ppm).

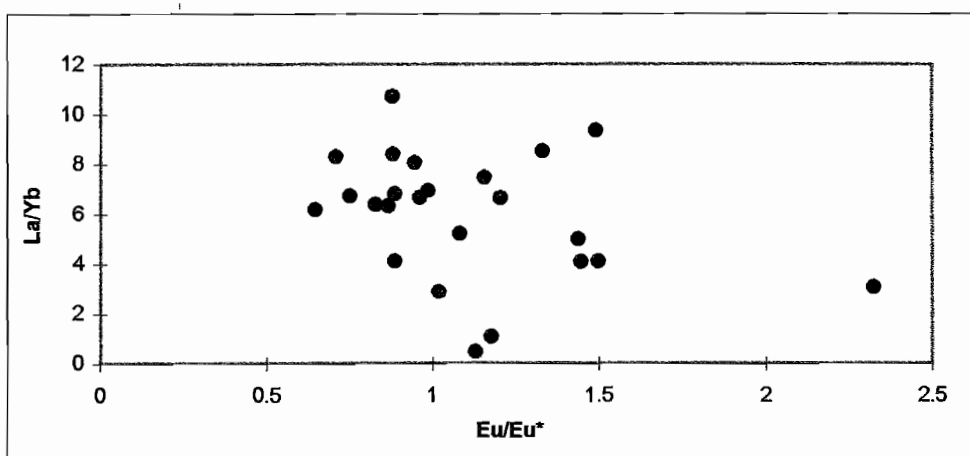
Figure 37 shows Eu/Eu* results as profiles plotted against Eastings along the length of the hydrothermal system and as a scattergram of normalised La/Yb and Eu/Eu* ratios. On some section lines more than one sample was collected, usually at different levels through the Liontown Horizon. As a result the profile data has been displayed as two profiles, one using maximum Eu/Eu* for each station along the horizon and the other using the average Eu/Eu* results. Both profiles show a moderate positive anomaly over the deposit centred at 9900E. From these profiles it appears the vectoring potential of Eu/Eu* in the altered siltstones is limited. A significant though discrete europium anomaly is developed over the Liontown



[a] Average Eu/Eu* intensity along the Lontown exhalative horizon over a strike length of 6.5 kms.



[b] Maximum values of Eu/Eu*



R = -0.33

[c] La/Yb vs Eu/Eu* scattergram for data series used in plots [a] and [b].

Figure 37 : Lontown Horizon sericitic siltstones - Eu/Eu* Profiles and La/Yb vs Eu/Eu* scattergram.

deposit though there is little or no anomalism beyond the eastern and western margins of the mineralised system (i.e. 9500E and 10700E). A weak trend of increasing Eu/Eu^* ratios is observed from 11000E to 14000E and this may relate to the weakly developed Panthertown stringer system centred at 13000E. Nevertheless this trend is subtle and given the limited number of data points is relatively ambiguous. Certainly the current data set does not show any significant increase in Eu/Eu^* from distal to proximal locations with respect to the Liontown deposit. Despite the apparent lack of vectoring potential there does appear to be a good correlation with the Eu/Eu^* trends shown in Figure 37a and the relative temperature profile in Figure 26b.

Figure 37c shows an essentially random scatter of La/Yb vs Eu/Eu^* for the entire data set. If a significant proximal to distal trend were present a negative correlation of high La/Yb to high Eu/Eu^* would be expected.

11.0 REE DEPLETION PATTERNS IN THE FOOTWALL PUMICE BRECCIAS

In sections 10.2 and 11 I have investigated the application of positive europium anomalies as exploration tools. As previously discussed the exhalative portion/s of a VHMS hydrothermal system can be enriched in europium and the footwall rocks in turn depleted, showing negative europium anomalies. Normal igneous and sedimentary processes generate rocks with overall negative or flat rare earth element slopes and may often have a negative europium anomaly (Rollinson, 1993). The Mount Windsor Rhyolite is a good example of a volcanic rock with a negative europium anomaly due to preferential extraction of divalent Eu during plagioclase fractionation or the retention of Eu in residual plagioclase during melting of a crustal source (Stolz, 1991). It follows that based on their REE signature, rocks with pre-existing negative europium anomalies will be difficult to discern from rocks with negative Eu anomalies due to hydrothermal alteration. Schade et al (1989) suggest that in large hydrothermal systems the HREE may experience preferential enrichment/mobilisation (possibly by F or CO_2 complexing) resulting in birdwing shaped REE profiles. These birdwing profiles have a negative LREE trend, negative inflection point at Eu and a flat to

positive HREE trend, which may enable discrimination between REE profiles due to fractionation processes and those related to hydrothermal alteration where Eu^{2+} and the trivalent HREE are mobilised.

Stolz (1991) provides REE profiles of both fresh unaltered Mt Windsor rhyolite and hydrothermally altered equivalents from the Thalanga footwall. The altered rhyolites from the footwall of the Thalanga deposit have birdwing profiles with flat to weakly positive HREE trends whereas the unaltered rhyolites have a consistently negative slope over the complete LREE to HREE series. Stolz (1991) notes that the relative depletion of Eu in the andesitic sericite schist from the Waterloo footwall is relatively small when compared with the altered Thalanga rhyolites. He also points out this is consistent with the suggestion of Campbell et al (1984) that the degree of depletion is related to the size of the alteration system and associated ore body.

At Liontown the REE profiles of the altered dacitic pumice breccias below the massive sulphide lodes have significant negative europium anomalies. The relative depletion of Eu is of a similar magnitude to that seen at Thalanga, however there is no consistent development of the birdwing geometry in the profiles. That is, the HREE maintain a negative slope. From these results it would seem the size of the negative Eu anomaly (Eu/Eu^*) is not a guide to the size of orebody present within an alteration system, as Liontown is a relatively small orebody with a large Eu/Eu^* ratio and Thalanga a large orebody with a large Eu/Eu^* , though both do have laterally extensive footwall alteration systems. Perhaps as suggested by Schade et al (1989) the presence of a birdwing profile with elevated HREE is a better guide to the size of the orebody present.

The REE study of the Liontown footwall lithologies was undertaken to investigate the vectoring capacity of negative europium anomalies within the footwall alteration system. The distribution of alkali, precious and base metals was examined during the course of the exploration programme though generally found only erratic geochemical patterns within the main alteration envelope.

To study the variation of the REE's vertically through the alteration system two diamond holes were selected for sampling to provide representative sections through the pumice breccias. Hole LLD 136 is located on section 10265E and also intersects the subhalative

Carrington lode which at this point is developed 39 metres below the Liontown Horizon-Pumice Breccia interface (Plate 1). Hole CGD001 is located in the less intense Cougartown alteration system which is situated 300 metres to the north of the Tigertown stratiform mineralisation. In total 18 samples were collected and analyses were undertaken by ICP-MS at ALS (Brisbane).

Results and Interpretation:

Figure 38 shows a series of rare earth element spidergrams through altered pumice breccias, commencing 10m below the **Liontown Horizon**, passing through the **Carrington Lode** and finishing with the last sample located 88 metres into the footwall (Appendix, Table 14). The spidergrams for depths 134, 144 and 154m each have a strongly negative europium anomaly with sample 144m showing a near birdwing profile. Sample 166m represents massive sulphide from the Carrington lode and has an overall negative slope, with a negative samarium anomaly. It is pertinent to mention the Carrington lode does not have a strong positive europium ($\text{Eu}/\text{Eu}^* = 1.21$) anomaly unlike the exhalative lodes of the Liontown Horizon. The absence of a strong positive europium anomaly further augments the proposed sub seafloor replacement model.

Below the Carrington lode there are significant negative europium anomalies at depths 170 and 184m. Below the 184m station, Eu anomalies start to decline. The spidergrams do not show europium anomalies at 192, 204 and 214m despite the intensity of alteration remaining relatively high as indicated by the corresponding $\text{Na}_2\text{O}\%$ and alteration index profiles. The alteration index used is that developed by Ishikawa et al (1976) $\text{AI} = ((\text{K}_2\text{O} + \text{MgO})/(\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO} + \text{MgO})) \times 100$, the more intense the alteration, the larger the alteration index (AI) value (Appendix, Table 14).

The data shown in Figure 38 for drillhole LLD136 suggest there is a strong negative europium anomaly developed in the first 20 metres of pumice breccia immediately underlying the Liontown Horizon and a less intense negative anomaly present up to 18 metres below the Carrington lode. These results do not suggest the REE's have broad scale vectoring potential. However they may be useful when drilling for essentially blind subseafloor replacement mineralisation such as the Carrington lode. That is downhole REE analyses in conjunction with other geochemical data may give an indication as to whether or

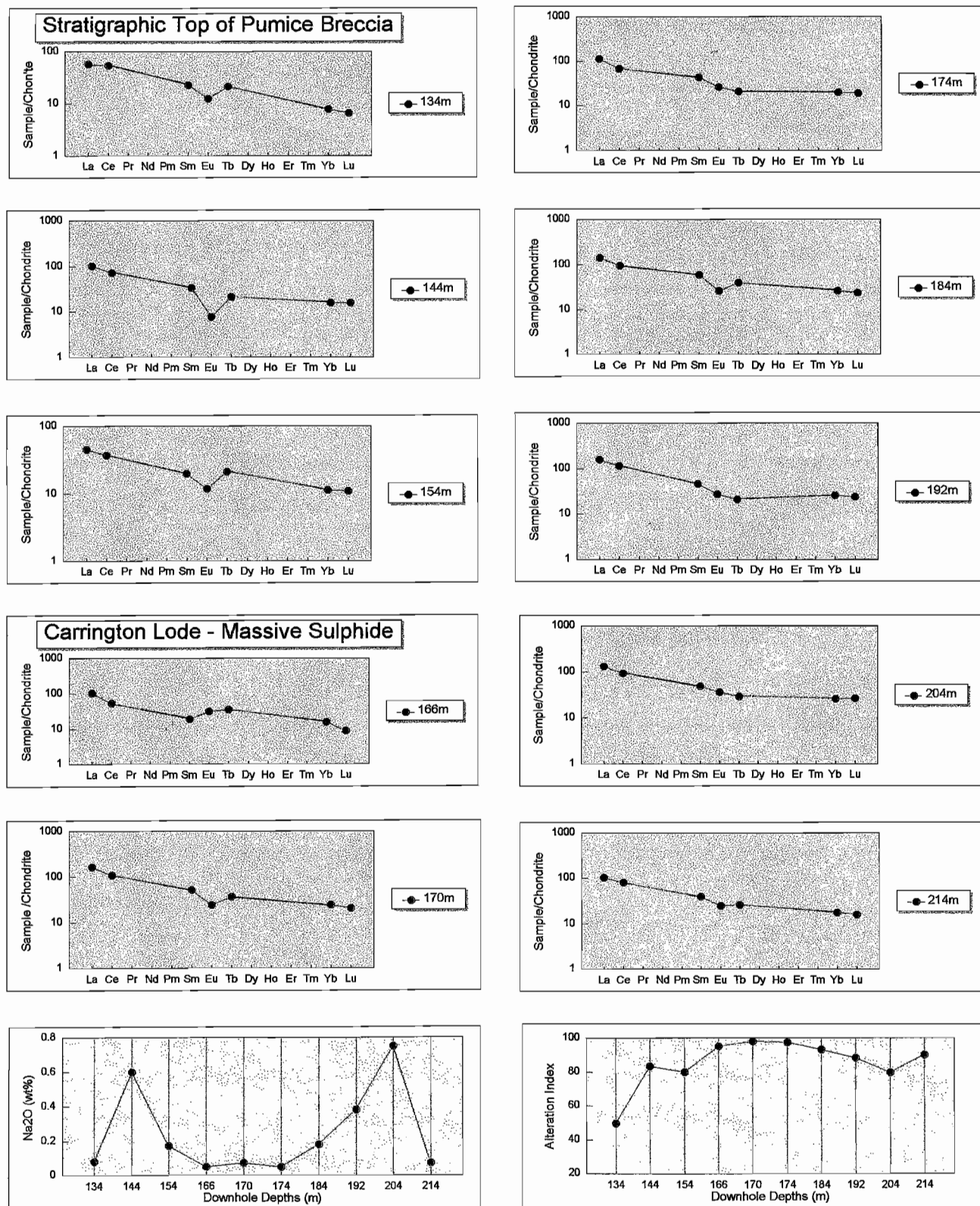


Figure 38: Liontown Footwall Pumice Breccia - REE Spidergrams and Na₂O% - AI profiles for REE stations. Data from Drillhole LLD136.

not a drillhole has been drilled deep enough into the footwall system. $\text{Na}_2\text{O}\%$ may be uniformly low and base metals assays erratic whereas the europium anomaly may be present as a footwall halo developed up to 20 - 30 metres below the orebody. Thus a drillhole terminated in altered pumice breccia with a significant negative Eu/Eu^* anomaly may warrant extending a further 20-40 metres.

Given that these results and interpretation are based on one drillhole I suggest follow up REE profiles are undertaken across the Liontown footwall system to confirm the preliminary trends observed.

At **Cougartown** a similar investigation was undertaken on drillhole CGD001 (Plate 1). The drillhole is collared 300 metres stratigraphically below and to the north of the Tigertown exhalative mineralisation and was originally targeted on a gossanous zone representing weak stringer-blebby sphalerite mineralisation deep within the pumice breccia sequence which is footwall to the Tigertown mineralisation. The hole is drilled in a southerly direction from footwall to hangingwall. The geological and geochemical results suggest the Cougartown area comprises a series of stratabound alteration zones that alternate between silica augen-chloritic, lenticle textured (strongly altered) pumice breccias and their less altered equivalent feldspar phyric-pumiceous-lithic bearing, silica-albite altered dacitic breccias. Figure 39 shows a series of REE spidergrams and a downhole $\text{Na}_2\text{O}\%$ profile for hole CGD001 (Appendix, Table 14). The depth interval 60 to 149m comprises silica augen-chloritic lenticle textured pumice breccia with $\text{Na}_2\text{O}\%$ in the range 0.15 - 0.5%, the interval 149 to 210m consists of the silica-albite altered feldspar phyric equivalent, with $\text{Na}_2\text{O}\%$ in the range 2 to 4.5%.

The REE spidergrams for the more altered zone 27 - 120m generally show weak to moderately negative europium anomalies where Eu/Eu^* varies from 0.53 to 0.81 and includes a single sample at 110m with a weakly positive anomaly of 1.20. In contrast the moderate to strongly negative anomalies from Liontown have Eu/Eu^* ratios in the range 0.28 to 0.57. The less altered zone 153 - 210m in CGD001 shows only weakly negative europium anomalies in the range 1.00 to 0.68. At Cougartown there is only a weak relationship developed between intensity of europium depletion and the intensity of feldspar destruction as shown by the downhole $\text{Na}_2\text{O}\%$ vs depth profile.

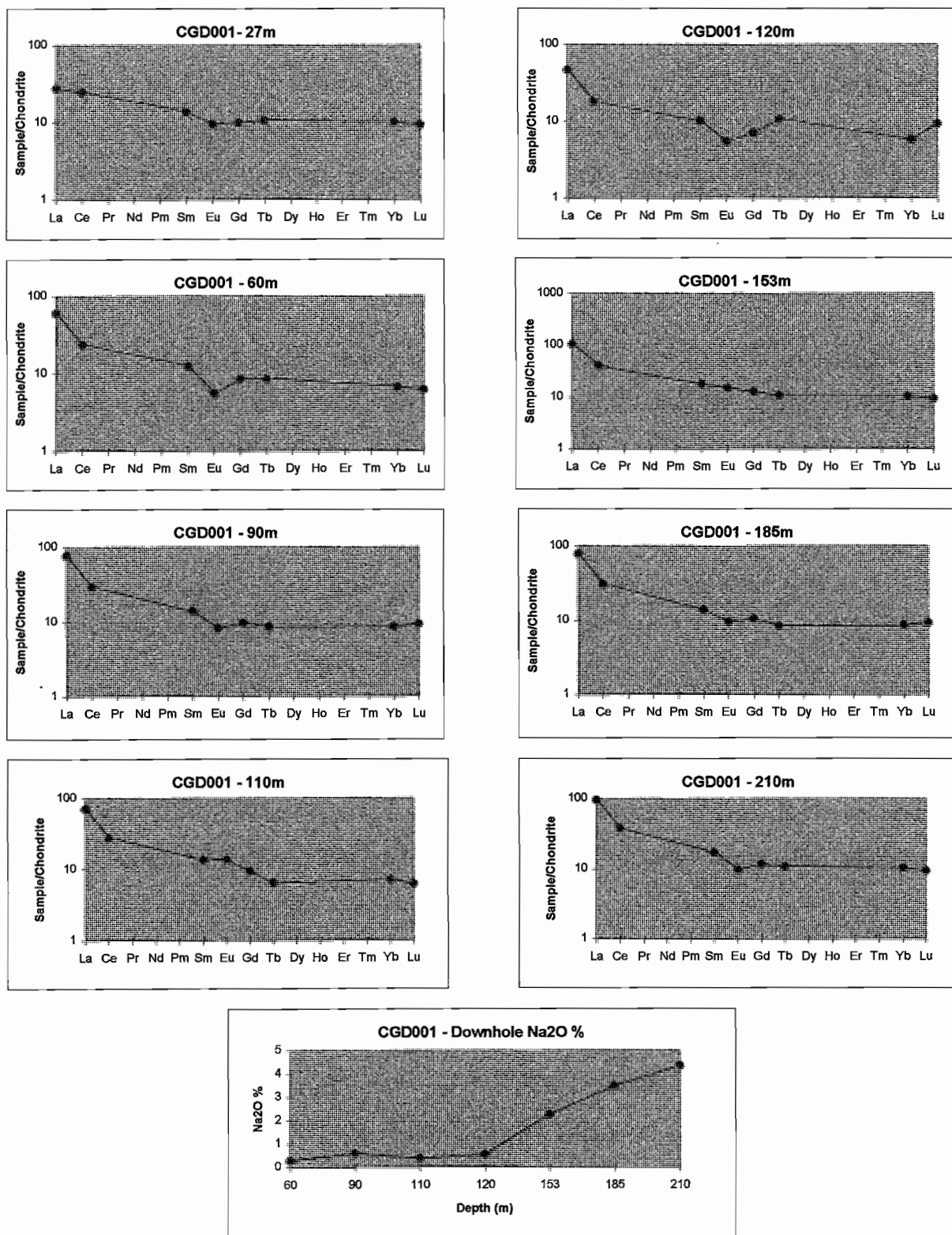


Figure 39: Cougartown REE spidergrams through variably altered pumice breccia sequence. Samples CGD001 27,60,90,110 and 120m represent moderately silica-sericite-pyrite altered pumice breccia whereas samples CGD001 153,185 and 210m are weakly silica-albite feldspar phytic pumice breccia.

12 CONCLUSIONS

The Liontown deposit occurs close to the stratigraphic top of the Trooper Creek formation and is located adjacent to the Oak Creek growth fault. The Cougartown-Tigertown and Panthertown satellite hydrothermal systems occur on the Liontown time equivalent horizon and the Leopartown system is located on a separate horizon 700-800 metres stratigraphically below the Liontown Horizon.

Liontown is clearly a volcanic-associated massive sulphide deposit comprising both seafloor exhalative and subhalative mineralisation. Sulphur, lead, oxygen and carbon isotope data is consistent with VHMS type mineralisation. The Liontown deposit is temporally associated with the change from dacitic to rhyolitic volcanism and may have a more shallow water setting than previously considered. Mineralisation at Liontown occurs at and below the contact of a silica-sericite-pyrite altered dacitic pumice breccia unit and an overlying sericitic-pyritic siltstone (Liontown Horizon).

The Liontown Horizon hosts three stratiform base metal sulphide lodes. The upper lode is interpreted from textural and mineralogical evidence to have been deposited from the exhalation of hydrothermal fluids onto the seafloor. There is no unequivocal evidence to show whether the central and lower lodes were formed by seafloor exhalative processes, or alternatively by near seafloor replacement.

Metal zonation and isopach studies of the Liontown Horizon suggest the exhalative/stratiform mineralisation was vented onto the seafloor on the edge of a paleo-ridge (10,060E) and migrated down slope to the west and southeast. A subsidiary stringer zone is also identified at 10550E though does not appear to be associated with exhalative sulphides.

The Carrington Lode occurs 20-30 metres below the Liontown Horizon - pumice breccia interface. The lode is a sub-seafloor replacement body of massive to semi-massive sulphide interpreted to have formed by the eastward lateral migration of hydrothermal fluids preferentially through an ashy and feldspar-bearing volcanoclastic horizon. The associated black Mg-chlorite alteration is inferred to mark a zone of seawater-hydrothermal fluid mixing. The Liontown footwall sequence has been shown to comprise a series of dacitic

volcaniclastic mass flow units, primary textural evidence from the Cougartown area demonstrates the protolith is a feldspar phyric pumice breccia.

The peripheral alteration/mineralised systems at Tigertown, Cougartown, Panthertown and Leopards town have each been characterised as VHMS related. The Tigertown-Cougartown area is interpreted as a low temperature ($<200^{\circ}\text{C}$), oxidised VHMS system that struggled against relatively high sedimentation rates. The system is small with limited potential for the discovery of significant massive sulphide.

The Leopards town alteration system is considered pre-Devonian with a probable Cambro-Ordovician VHMS origin. Leopards town appears to be a stratabound stringer zone developed in a sequence of dacitic volcaniclastics and siltstone. The system is interpreted, from elevated Cu-Au in pyrite stringers and from the relatively high temperature estimates derived from whole rock oxygen isotope values to have formed from relatively hot ($>300^{\circ}\text{C}$) hydrothermal fluids, probably not conducive to the deposition of lead and zinc sulphides. There is no evidence to suggest that an exhalative horizon was developed at Leopards town, however further potential for the discovery of a base metal sulphide deposit may exist along strike to the southwest in the vicinity of the Oaky Creek growth fault. The Leopards town area may be more prospective for Reward type Cu-Au pipe mineralisation.

A study using whole rock oxygen isotope data collected along the footwall alteration system indicates that this technique has good vectoring potential to zones of higher hydrothermal temperature. Refinement of the raw data through the calculation of relative temperature estimates is demonstrated as an important data manipulation procedure, particularly for data sets where the sample mineralogy is highly variable.

The Liontown carbonate exhalative facies and the sericitic siltstones of the 'favourable horizon' each have positive europium anomalies ($\text{Eu}/\text{Eu}^* > 1$). In the immediate Liontown deposit area a proximal to distal trend was observed in the carbonate europium data set suggesting there is some scope to develop the intensity of Eu/Eu^* as a vectoring tool. The Eu/Eu^* anomalies are less pronounced and somewhat erratic in the sericitic siltstones. Their vectoring potential appears to be low though a higher density of sampling is required to confirm these results.

Significant rare earth element depletion patterns in the altered footwall pumice breccias of the Liontown deposit are developed up to 20 metres below massive sulphide mineralisation of both the exhalative and subhalative lodes. Negative Eu/Eu* anomalies may have vectoring potential in near ore environments where other geochemical indicators are erratic or nonresponsive. Follow up sampling and analysis is recommended.